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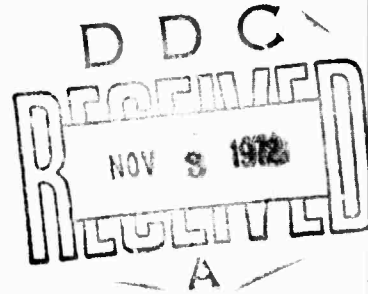


TRANSMISSION EXPERIMENTS IN PRAIRIE SMOKE (U)

Aeronomy Corporation

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TRANSMISSION EXPERIMENTS IN PRAIRIE SMOKE (U)

S. A. Bowhill  
E. E. Mendenhall

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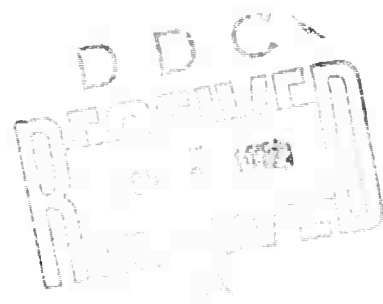
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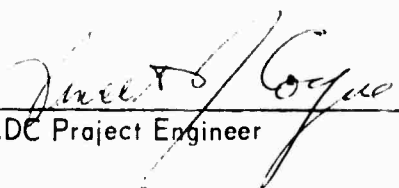
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## PUBLICATION REVIEW

This technical report has been reviewed and is approved.

  
RADC Project Engineer

  
RADC Contract Engineer

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ABSTRACT (U)

(S) During October 1971, as part of Prairie Smoke I, measurements were made of signals transmitted through the artificially heated F layer over Platteville from a geostationary satellite at 137 MHz; the morphology and motion of the artificial spread F (ASF) irregularities were deduced by spaced-receiver measurements of that signal. Similar information was gathered in December 1971 and February 1972 (Prairie Smoke Ib) using orbital satellites to give the altitude and orientation of the irregularities. Preliminary results only from Prairie Smoke Ib are included in this report.

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## 1. INTRODUCTION

(S) This paper describes the results of two types of experiment designed to study the nature of the irregularities produced by the ionospheric heating transmitter located at Platteville, Colorado. Two types of experiment were used. In the first, signals from a geostationary satellite at 137 MHz were examined by means of a set of spaced receiving antennas on the ground, the line of sight passing through the disturbed region of the ionosphere. In the second, signals from an orbiting satellite at 150 MHz were received at a point such that its line of sight intersected the disturbed region in the ionosphere.

(U) The detailed objectives of these experiments are set out in Section 2; Section 3 describes the location, experimental design, and the types of instrument used; the results of the geostationary and orbital experiments are described in Section 4 and 5, and are interpreted in Section 6; conclusions are given in Section 7.

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## 2. OBJECTIVES OF THE EXPERIMENTS (U)

(S) The satellite transmission experiment has been suggested by Bowhill, et al. (1971) as a suitable way to obtain information leading to a morphological model (and hence a radar-scattering model) of the irregularities produced by ionospheric heating. The objectives of this experiment were further reviewed by Bowhill (1971) and it was pointed out that two types of experiment could be carried out; a geostationary experiment and an orbital experiment. These experiments share the concept that a frequency is chosen high enough to justify neglecting diffraction effects, thereby allowing geometric optics to be used; and high enough also for the phase fluctuations observed at the ground to be less than a radian, permitting shallow-diffraction-screen theory to be used (Bowhill, 1961).

(S) Ionospheric heating apparently produces two kinds of irregularities in the F region of the ionosphere. The first consists of field-aligned variations of ionization (striations) with a spatial period normal to the magnetic field of about 1 km, probably extending through the entire F region; because of the similarity of this phenomenon to naturally-occurring spread F, it has been called artificial spread F (ASF). The second is a much finer structure, capable of producing backscatter at UHF, and apparently associated with the increased attenuation of HF radio signals reflected from the ionosphere; it has been called "wide-band attenuation" (WBA).

(S) For each of these types of irregularities (ASF and WBA) it is important to determine:

1. Whether the structure is field-aligned.
2. Dimensions and orientation of the correlation ellipsoid associated with the various structure sizes present.

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3. Relative intensity of the electron-density fluctuations as a function of altitude.
4. Large-scale horizontal variation of fluctuation intensity in the north-south and east-west directions (the horizontal extent).
5. Variations of the quantities with time when the heater is switched on or off.
6. Drift velocity of the electron-density fluctuations.

These are minimum requirements to establish a scattering model of the irregularities. The following additional objectives are important from the point of view of possible systems applications:

7. Intensity and time scale of amplitude fluctuations of signals transmitted through the heated region as a function of wave frequency.
8. Magnitude of angle-of-arrival scintillations for various frequencies of transmitted wave.
9. Occurrence of multipath effects, such as multipath scintillations or off-line-of-sight scatter.
10. Off-frequency scatter of UHF signals.
11. Degradation of various types of modulation transmitted through the heated region.

When yield studies of WBA and ASF are initiated, the following additional objectives will be appropriate:

12. Effect of transmitter parameters such as heater frequency, power and modulation on the intensity of the electron-density fluctuations in WBA and ASF.
13. Horizontal distribution of irregularities produced by off-vertical antenna beam patterns for the heater transmitter.
14. Efficacy of new antenna concepts for the heater, such as the scanned-fan beam.

(S) These objectives can be accomplished, in the main, by amplitude measurements of satellite signals at carefully selected locations, supplemented by interferometric measurements of relative phase at two closely-spaced antennas. Table 2.1 illustrates the applicability of the orbital and geostationary configurations to these objectives.

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Table 2.1

Potential (P) or demonstrated (D) applicability of the satellite transmission experiment to the various objectives using amplitude measurements from 1-3 antennas, or an interferometric pair (I).

	<u>Objective</u>	<u>Geostationary</u>				<u>Orbital</u>			
		<u>1</u>	<u>2</u>	<u>3</u>	<u>I</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>I</u>
1.	Field alignment			D				D	
2.	Size and orientation			D			D	D	
3.	Altitude distribution						D	D	
4.	Horizontal extent	D				D			
5.	Onset and decay	D	D	D					
6.	Drift velocity		D	D					
7.	Fading with frequency	P				P			
8.	Angle flutter with frequency				P				
9.	Multipath effects	P				D			
10.	Off-frequency scatter	P				P			
11.	Modulation degradation	P				P			
12.	Heater parameters	P				P			
13.	Off-vertical heating	P				P			
14.	New antenna concepts	P				P			

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## 3. EXPERIMENTAL CONFIGURATIONS (U)

(S) During Prairie Smoke I, because of the relatively short time available to mount a field experiment, attention was concentrated on implementing a mobile geostationary satellite receiving station. It consisted of a 23' Concord travel trailer, with a 5-kW diesel alternator as power supply, providing a completely mobile installation. Transmissions from the ATS-5 satellite on its telemetry frequency of 136.47 MHz was received on three specially constructed 6-element circularly-polarized Yagi antennas mounted on tripods, with battery-operated Vanguard dual-gate MOSFET RF converters for each antenna. Spacings up to 300 m were used (see Section 4). The receivers used were Allied Radio type AX-190 solid-state crystal-controlled amateur receivers modified for linear detector output. Signals were recorded on a dual-channel Hewlett-Packard 7702B thermal-writing recorder; failure of one channel necessitated the use of an Ampex battery-operated cassette recorder for some of the data.

(S) Two rural sites were used, in the vicinity of Newcastle and Lance Creek, Wyoming. On Figure 3.1, a meridional section through Platteville shows the lines of sight to the ATS-5 satellite from Newcastle and Lance Creek. Contours of ionospheric heating calculated by Meltz and LeLevier (1970) have been superposed on the diagram. Curved-earth corrections have been made to the altitudes over Platteville (though the lines of sight have been drawn straight for simplicity).

(S) The orbital experiment was carried out separately on December 6, 1971, without a mobile receiving station. Dual circularly-polarized turnstile antennas were used to receive signals from a US Navy navigational satellite at 149.88 MHz. The same models of RF converter and receiver were used as in the

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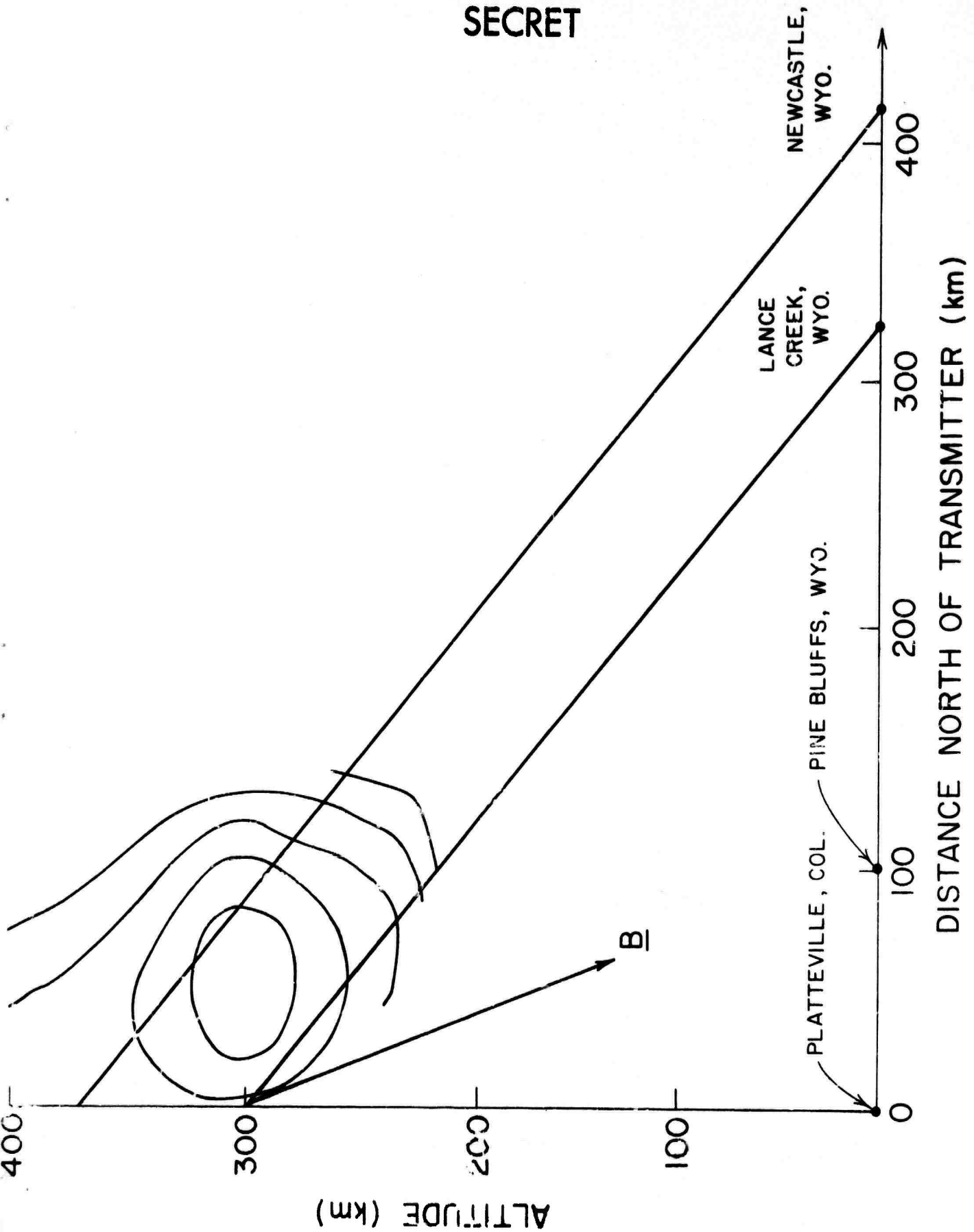


Figure 3.1  
Lines of sight for the geostationary experiment in Prairie Smoke I (U).

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geostationary experiment, the signals being recorded in real time on a thermal-writing recorder. The product detector BFO output of the receivers was recorded (together with WWV) on a Sony Type 366-4 4-channel tape deck. These signals were later played back through a Hewlett-Packard 310 A wave analyzer, acting as a tracking filter with 200 Hz bandwidth, and recorded on a thermal-writing recorder.

(S) The satellite orbit elements were provided for the satellite by NORAD, and the azimuth and elevation calculated by Lincoln Laboratory (Table 3.1) for a site at  $41.55^{\circ}\text{N}$ ,  $104.055^{\circ}\text{W}$ ; this being the location of the point whose geomagnetic field line passes over the heater transmitter at an altitude of 300 km. In fact (due to the lack of a second mobile field station) the nearest available site was a motel at Pine Bluffs, Wyoming, at a latitude of  $41.18^{\circ}\text{N}$ . An azimuth-elevation plot is shown, corrected for the changed location, in Figure 3.2.

(S) During Prairie Smoke Ib on February 14-17, 1972, further observations were made of the scintillation of signals at about 150 MHz. Since the periods of observation were limited by observational considerations, it was not possible to use a single receiving site for all four days. Accordingly, the nearest pass to overhead was selected. It was then assumed that the greatest intensity of fluctuation would be found when the satellite line of sight (LOS) passed through a point at 300-km altitude directly over Platteville. For the passes nearest to overhead, the satellite LOS was traced through the 300-km point to the surface of the earth. During the satellite pass, the intersection sweeps in a general N-S direction. The points for each day at which it intersected Interstate Route 80 were determined, and established as the observation point for each day; they are shown on Figure 3.3. Subsequent analyses of the satellite passes for each location (Table 3.2) showed that the LOS

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Table 3.1

## Satellite Orbit Elements:

Perigee	=	1029	Semi-major Axis	=	1.17025511
Julian Day	=	41287.83711624	SMA Dot	=	-.1312767E-06
Mean Anomaly	=	99.5169	SMA DotDot	=	.1840790E-13
Inclination	=	89.9887	Eccn Dot	=	-.11132E-06
Eccentricity	=	.0076090	Rt ASC Dot	=	-.00113
Right Ascension	=	278.8173	Arg Per Dot	=	-2.87455
Argument of Perigee	=	259.7345			

Site Location: 41.55°N, 104.055°W

Times are after 1300 MST on 6 December 1971

Time		Range (km)	Az (deg)	El (deg)	Time		Range (km)	Az (deg)	El (deg)
Min	Sec				Min	Sec			
26	0.	3909.7	177.3	.1	30	40.	2219.8	179.2	22.3
26	10.	3848.0	177.4	.7	30	50.	2163.2	179.3	23.4
26	20.	3786.2	177.4	1.3	31	0.	2107.1	179.5	24.7
26	30.	3724.5	177.5	1.9	31	10.	2051.6	179.6	26.0
26	40.	3662.8	177.5	2.5	31	20.	1996.8	179.7	27.3
26	50.	3601.1	177.6	3.1	31	30.	1942.6	179.9	28.7
27	0.	3539.5	177.6	3.7	31	40.	1889.2	180.0	30.2
27	10.	3478.0	177.7	4.4	31	50.	1836.7	180.2	31.8
27	20.	3416.5	177.7	5.0	32	0.	1785.1	180.4	33.4
27	30.	3355.0	177.8	5.7	32	10.	1734.4	180.6	35.1
27	40.	3293.7	177.8	6.4	32	20.	1684.9	180.8	36.9
27	50.	3232.4	177.9	7.0	32	30.	1636.6	181.1	38.7
28	0.	3171.3	177.9	7.8	32	40.	1589.5	181.4	40.7
28	10.	3110.3	178.0	8.5	32	50.	1543.9	181.7	42.7
28	20.	3049.3	178.0	9.2	33	0.	1499.9	182.0	44.9
28	30.	2988.6	178.1	10.0	33	10.	1457.6	182.4	47.2
28	40.	2928.0	178.2	10.8	33	20.	1417.2	182.9	49.6
28	50.	2867.5	178.2	11.6	33	30.	1378.8	183.4	52.1
29	0.	2807.3	178.3	12.4	33	40.	1342.7	184.0	54.7
29	10.	2747.2	178.4	13.2	33	50.	1309.0	184.8	57.5
29	20.	2687.4	178.5	14.1	34	0.	1277.8	185.7	60.4
29	30.	2627.8	178.5	15.0	34	10.	1249.5	186.8	63.4
29	40.	2568.5	178.6	16.0	34	20.	1224.1	188.3	66.5

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Table 3 continued

Time		Range (km)	Az (deg)	El (deg)	Time		Range (km)	Az (deg)	El (deg)
Min	Sec				Min	Sec			
29	50.	2509.5	178.7	16.9	34	30.	1202.0	190.2	69.6
30	0.	2450.8	178.8	17.9	34	40.	1183.2	192.9	72.9
30	10.	2392.4	178.9	18.9	34	50.	1168.0	197.0	76.2
30	20.	2334.5	179.0	20.0	35	0.	1156.4	203.6	79.5
30	30.	2276.9	179.1	21.1	40	10.	2216.5	355.7	23.1
35	10.	1148.6	216.1	82.5	40	20.	2273.4	355.9	21.9
35	20.	1144.7	242.1	84.8	40	30.	2330.7	356.0	20.8
35	30.	1144.7	284.3	85.1	40	40.	2388.4	356.1	19.8
35	40.	1148.5	314.6	83.1	40	50.	2446.5	356.2	18.7
35	50.	1156.3	329.1	80.2	41	0.	2505.0	356.3	17.7
36	0.	1167.8	336.7	77.0	41	10.	2563.7	356.4	16.8
36	10.	1183.0	341.2	73.7	41	20.	2622.8	356.5	15.9
36	20.	1201.7	344.1	70.4	41	30.	2682.1	356.6	15.0
36	30.	1223.8	346.2	67.2	41	40.	2741.6	356.7	14.1
36	40.	1249.1	347.7	64.1	41	50.	2801.4	356.8	13.2
36	50.	1277.4	348.9	61.2	42	0.	2861.4	356.9	12.4
37	0.	1308.4	349.9	58.3	42	10.	2921.5	356.9	11.6
37	10.	1342.1	350.6	55.5	42	20.	2981.8	357.0	10.8
37	20.	1378.1	351.3	52.9	42	30.	3042.3	357.1	10.1
37	30.	1416.4	351.8	50.4	42	40.	3102.9	357.2	9.3
37	40.	1456.7	352.3	48.0	42	50.	3163.6	357.3	8.6
37	50.	1498.9	352.7	45.7	43	0.	3224.4	357.3	7.9
38	0.	1542.8	353.1	43.6	43	10.	3285.3	357.4	7.2
38	10.	1588.3	353.4	41.5	43	20.	3346.3	357.5	6.5
38	20.	1635.2	353.7	39.5	43	30.	3407.4	357.6	5.9
38	30.	1683.4	354.0	37.7	43	40.	3468.5	357.6	5.2
38	40.	1732.8	354.2	35.9	43	50.	3529.7	357.7	4.6
38	50.	1783.2	354.4	34.2	44	0.	3590.9	357.8	4.0
39	0.	1834.7	354.6	32.6	44	10.	3652.2	357.8	3.3
39	10.	1887.1	354.8	31.0	44	20.	3713.5	357.9	2.7
39	20.	1940.3	355.0	29.6	44	30.	3774.9	358.0	2.2
39	30.	1994.3	355.2	28.2	44	40.	3836.2	358.0	1.6
39	40.	2048.9	355.3	26.8	44	50.	3897.6	358.1	1.0
39	50.	2104.2	355.5	25.5	45	0.	3959.0	358.2	.4
40	0.	2160.1	355.6	24.3	45	10.	4020.3	358.2	-.1

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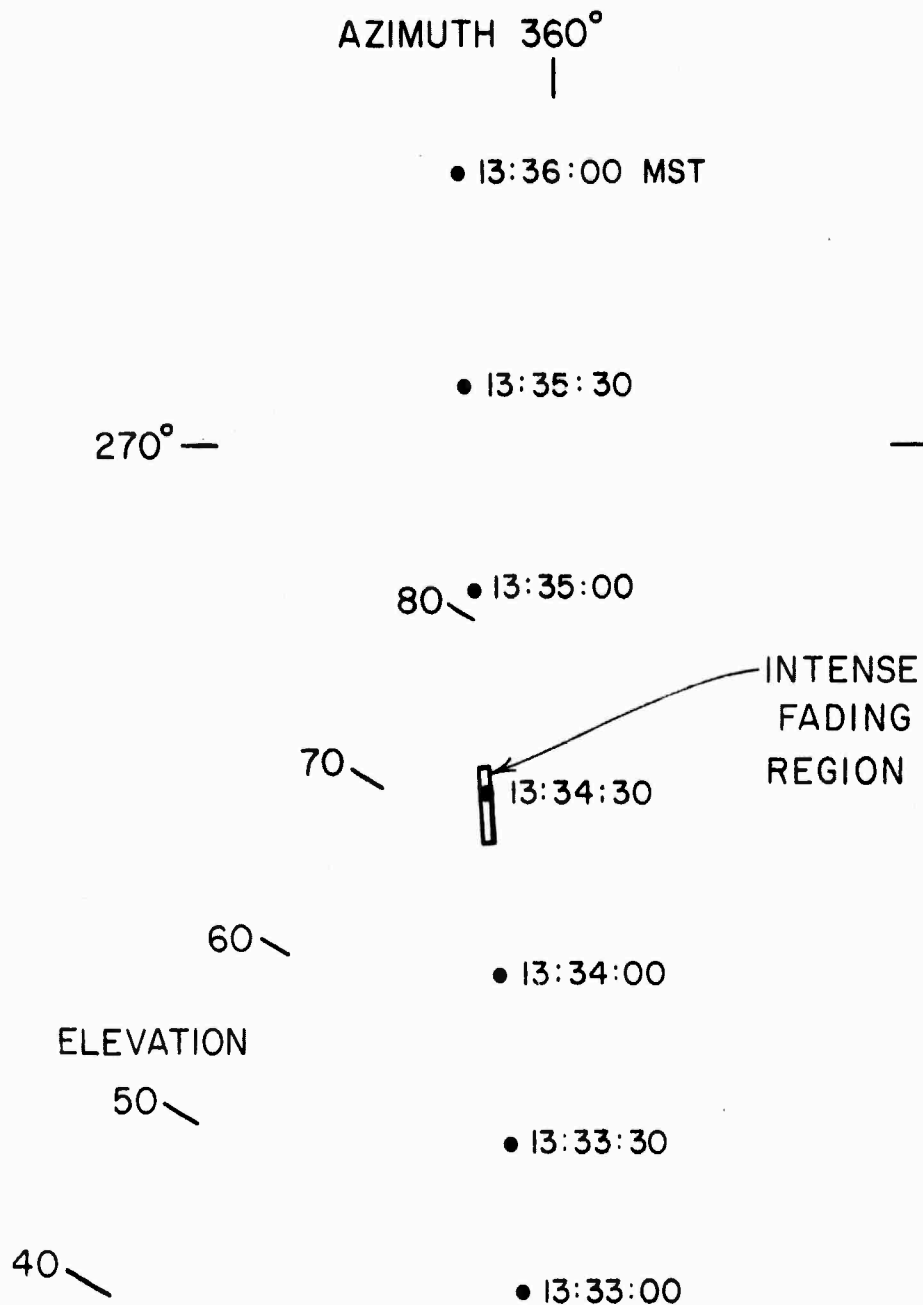
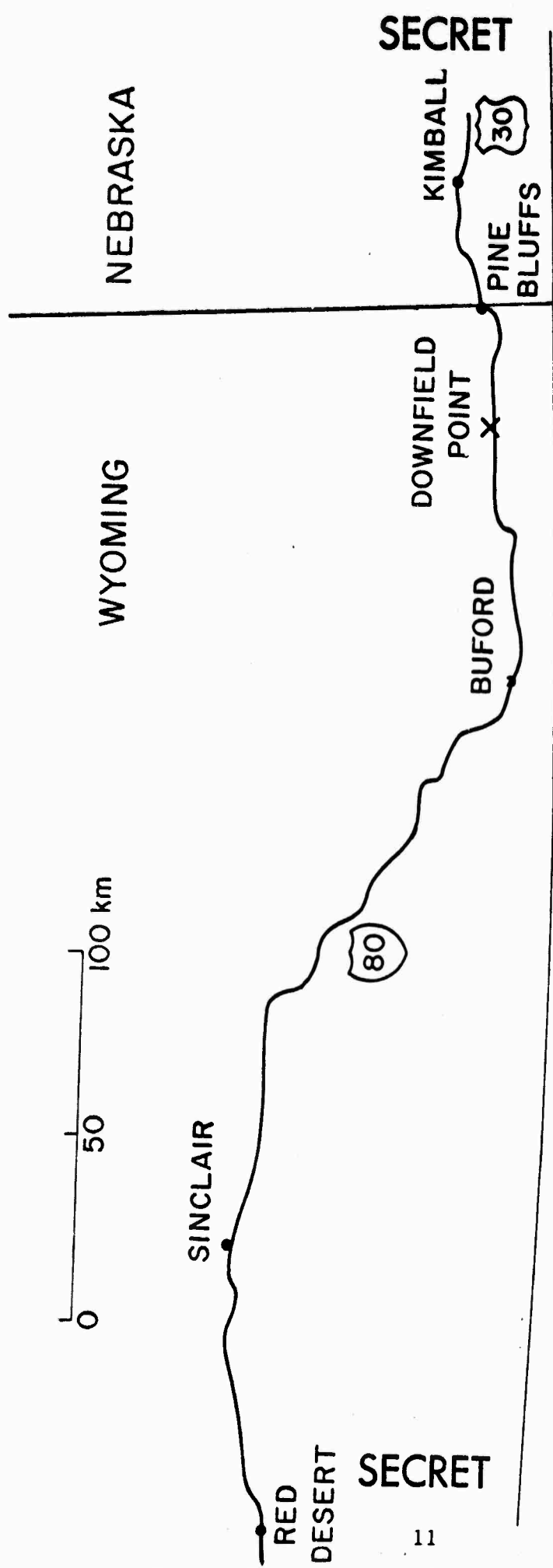


Figure 3.2

Azimuth-elevation plot for satellite passing over Pine Bluffs, Wyoming on 6 December 1971 (U).

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Table 3.2

SITE	RANGE TO TRANSMITTER km	LOS OVER TRANSMITTER		
		AZIMUTH	ELEVATION	HEIGHT
KIMBALL, NEB.	151.3	219.0	60.8	284.0
BUFORD, WYO.	109.4	158.2	70.0	316.1
SINCLAIR, WYO.	265.5	130.8	46.9	302.8
RED DESERT, WYO.	318.7	119.5	40.2	289.9

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passed over Platteville at altitudes of 284 to 316 km, in good agreement with the predictions.

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## 4. RESULTS OF GEOSTATIONARY SATELLITE EXPERIMENT (U)

(S) During the two weeks of PRAIRIE SMOKE I over 30 hours of data were obtained in the form of real-time chart recordings and magnetic tape recordings. Most of the data were obtained on October 13, 14, and 15 at the Newcastle site and on October 19 and 20 at the Lance Creek site. A variety of experimental difficulties contributed to the relatively small amount of data collected; primarily, the lack of time to adequately test the system components prior to deployment in the field.

(S) Spaced-antenna measurements were made at both locations with an east-west baseline. On October 20, three antennas were used with the third antenna to the north of the baseline so as to form an isosceles triangle (see Figure 4.1). Table 4.1 gives a summary of the antennas in operation and their separation for the days when data taken were of good quality.

### 4.1 Fading Intensity Results (U)

(S) Proper reduction of amplitude fading data to give a fading intensity as a percentage of the mean amplitude can most easily be accomplished by digital data reduction. Since this instrumentation is not yet available (but is expected to be by the time of the next series), a simple technique suitable for hand reduction was used; namely, the measurement of the third or fifth largest excursion in the amplitude during a one-minute or two-minute period. This, expressed as a percentage, gives a reasonable indication of average fluctuation of the amplitude.

(S) At Newcastle, the scintillation was almost nonexistent except when the transmitter frequency was close to  $f_oF_2$ . Therefore, only time intervals with time-correlated fading at the two antennas were identified. The average period (time between maxima in the amplitude fluctuations) and baseline time shifts

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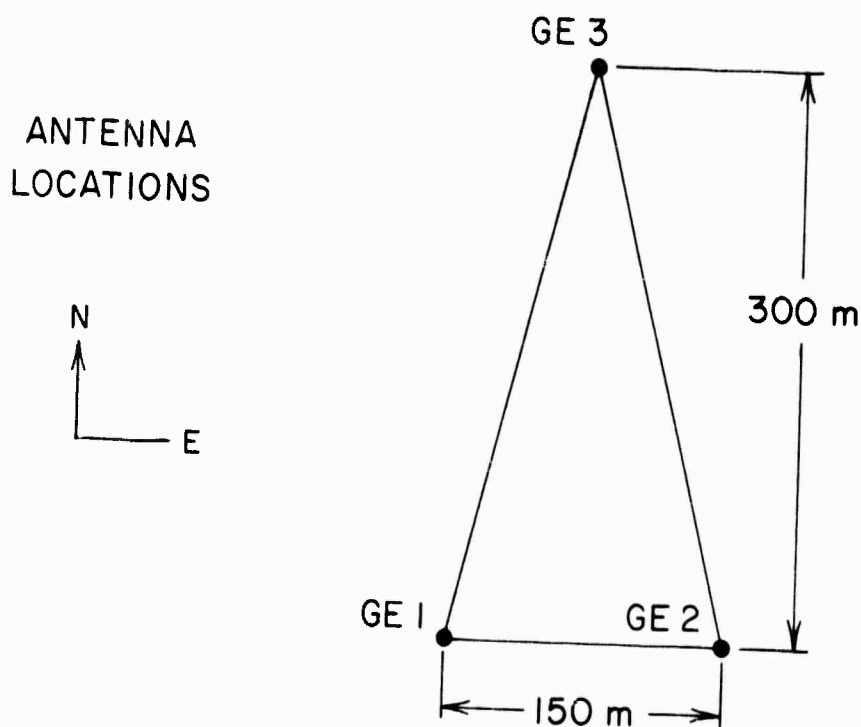
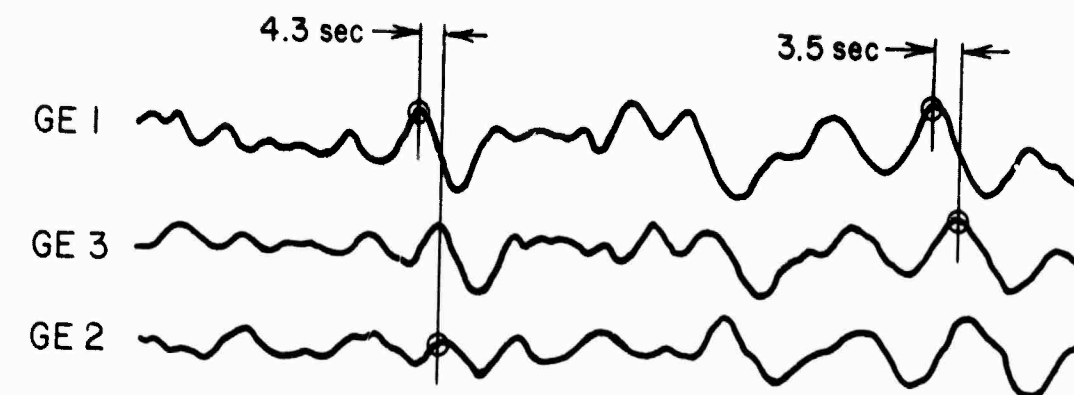


Figure 4.1

Illustrating time shifts between antennas in the geostationary experiment,  
1323-1325 MDT October 20, 1971 (U).

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Table 4.1

Availability of Scintillation Data (S)

<u>Date</u>	<u>Location</u>	<u>No.</u>	<u>Antenna , N-S Sep.</u>	<u>E-W Sep.</u>
13 Oct 1971	Newcastle	2	--	150, 300m
14 Oct 1971	Newcastle	2	--	300
15 Oct 1971	Newcastle	2	--	300
19 Oct 1971	Lance Creek	2	--	300
20 Oct 1971	Lance Creek	3	300m	150

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were examined for each interval. Only the amplitude (peak-to-peak) of the third largest excursion in each minute was recorded. This value divided by the dc level (mean signal amplitude) gave the fading intensity (I) for the minute. The maximum and average values of I were recorded for each interval when fading was observed. The signal-to-noise ratio, which was occasionally recorded, was sufficiently large and stable so as to be ignored in the above approximation.

(S) For the data taken at Lance Creek two-minute time intervals were examined, and the fifth largest excursion in each interval was measured and divided by the mean amplitude to give the fading intensity I. The resulting fading intensities are shown graphically in Figures 4.2, 4.3, and 4.4 for October 19 and 20. Evidently, the fading intensity increases quite rapidly as soon as the heating commences. Figure 4.5 illustrates this in more detail. The heating commenced at 1308 MDT, and by 1310 very substantial fading was present. Following the switchoff of the heater at 1325, there was a relatively gradual decrease in the fading intensity over a four or five minute period (the heater came on again at 1330).

(S) Figure 4.6 illustrates another case of the decay of fading following the cessation of heating at 1119 on October 20. It is interesting to note that longer-period fading persisted for some time after the shorter-period fading had disappeared.

## 4.2 Structure and Drift Results (U)

(S) As illustrated in Figure 4.1, when three spaced antennas were used, fading patterns were observed which were quite similar, but displaced in time by a few seconds. These data were analyzed by the method of similar fades, to give the size of the structure observed at the ground, and the direction and magnitude of movement of the irregularities. East-west and north-south time

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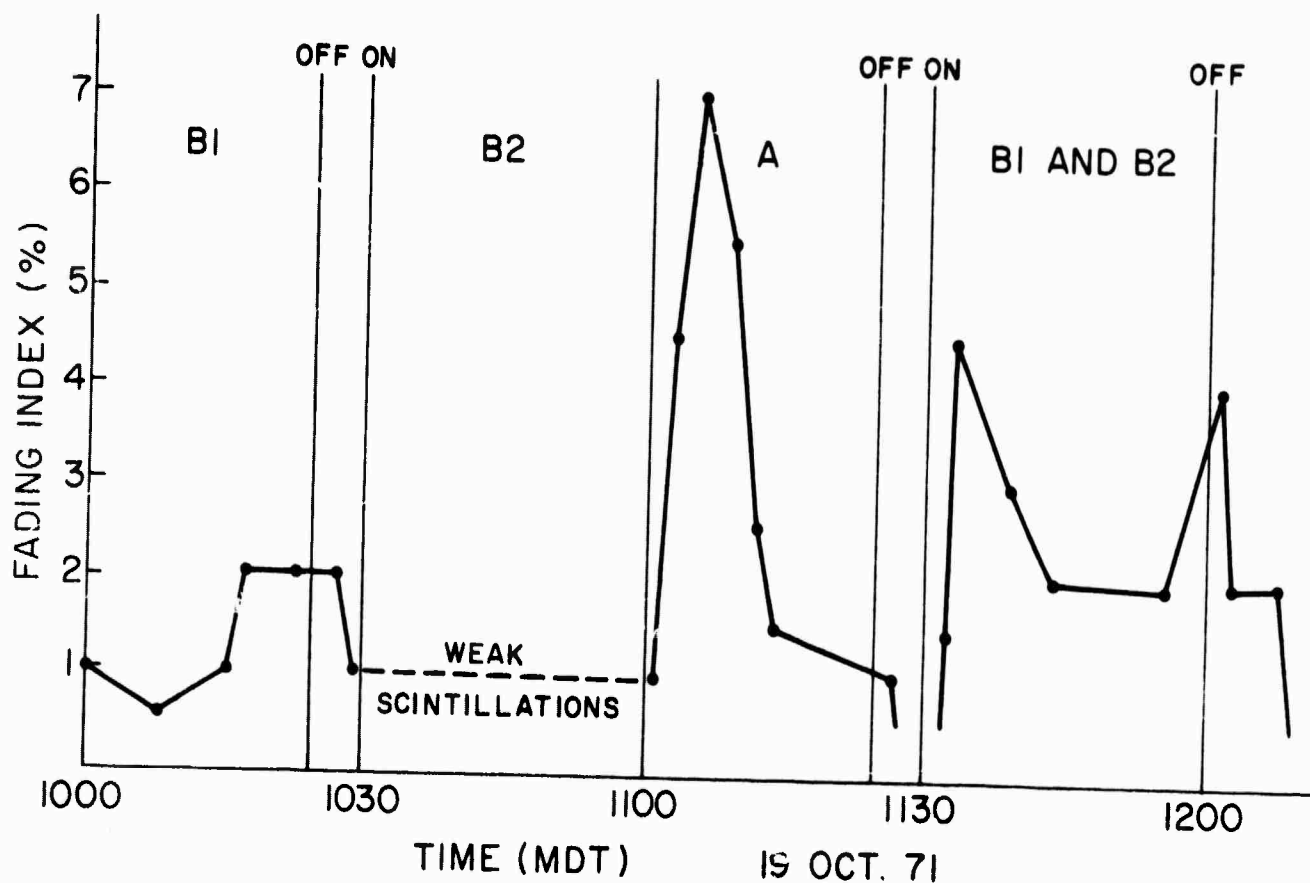
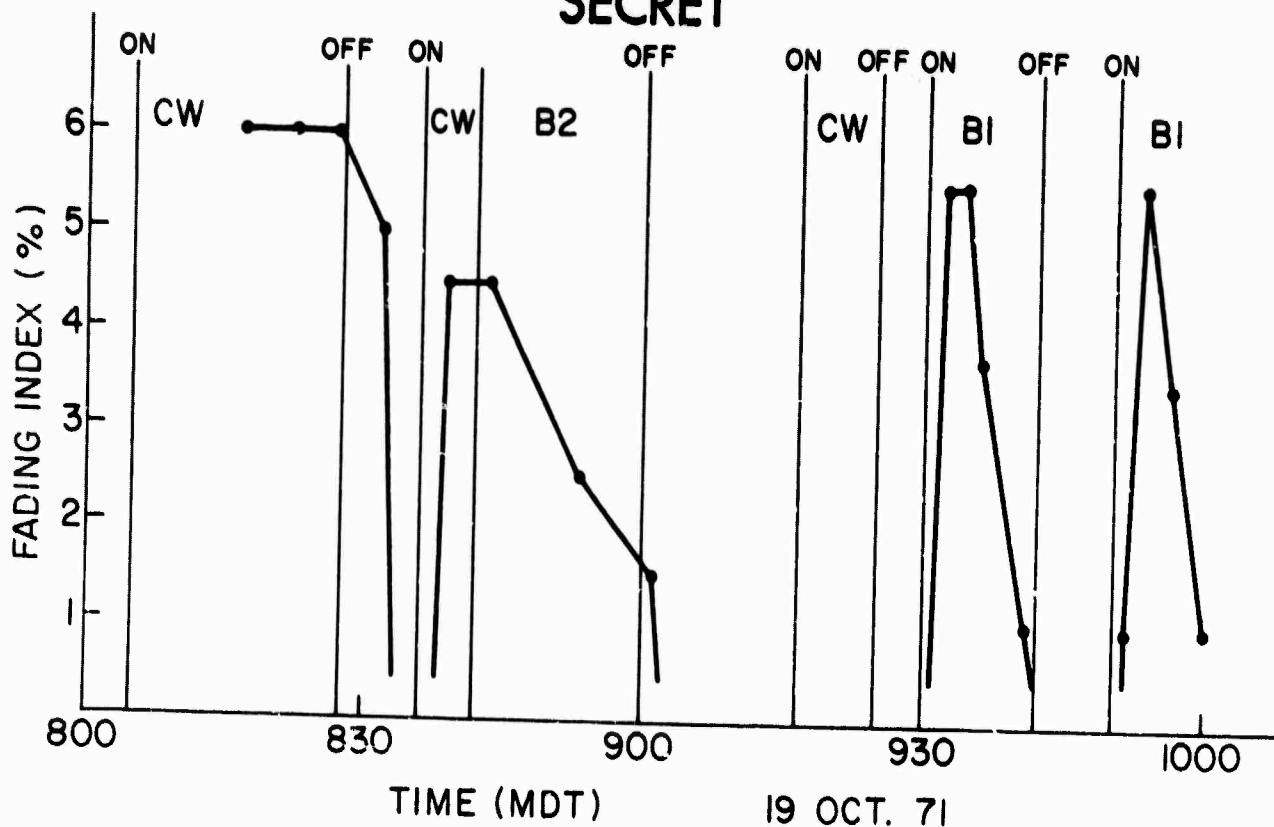


Figure 4.2  
Fading index, 0800-1200 MDT October 19, 1971 (U).

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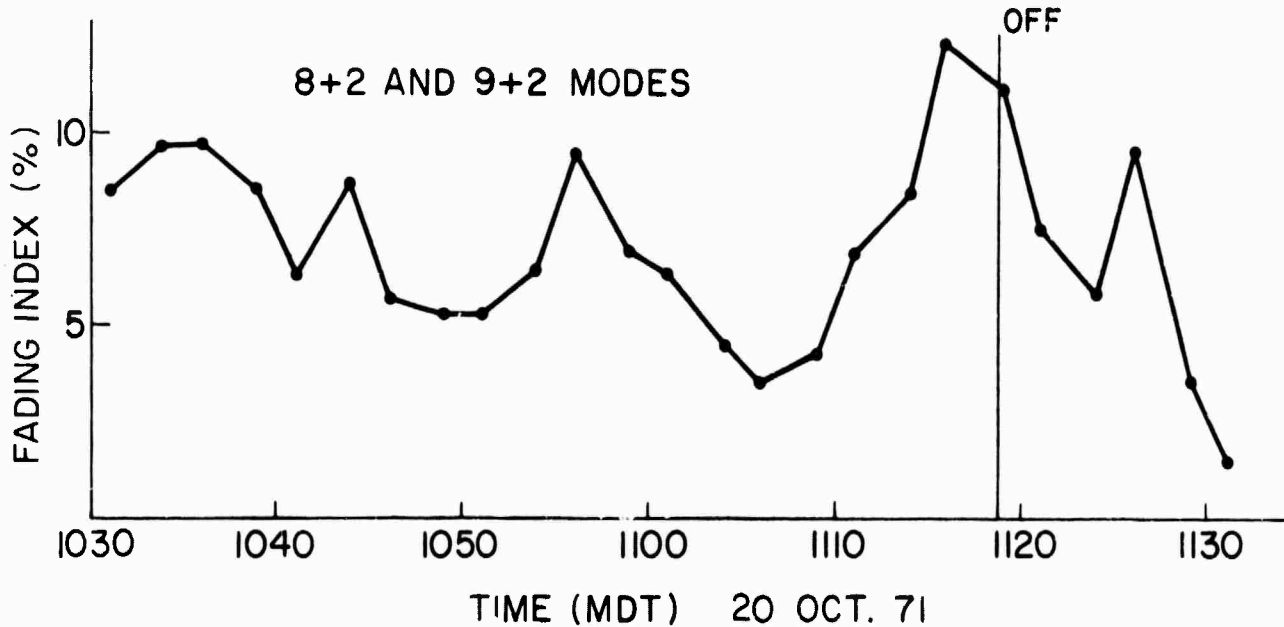
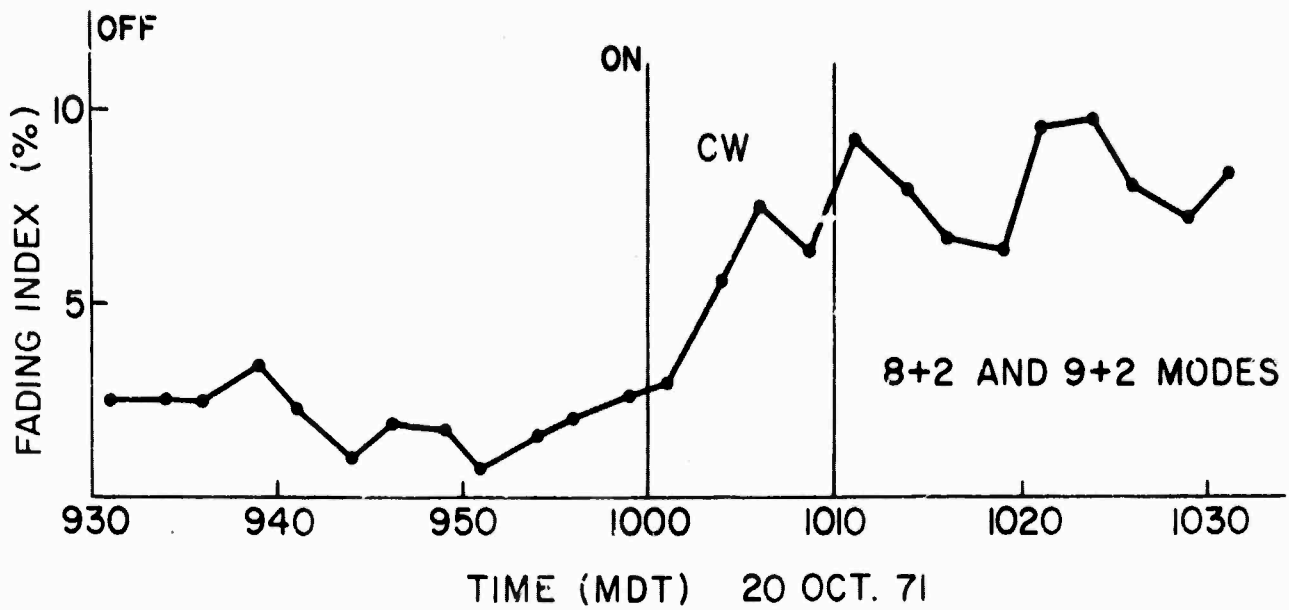


Figure 4.3

Fading index, 0930-1135 MDT October 20, 1971 (U).

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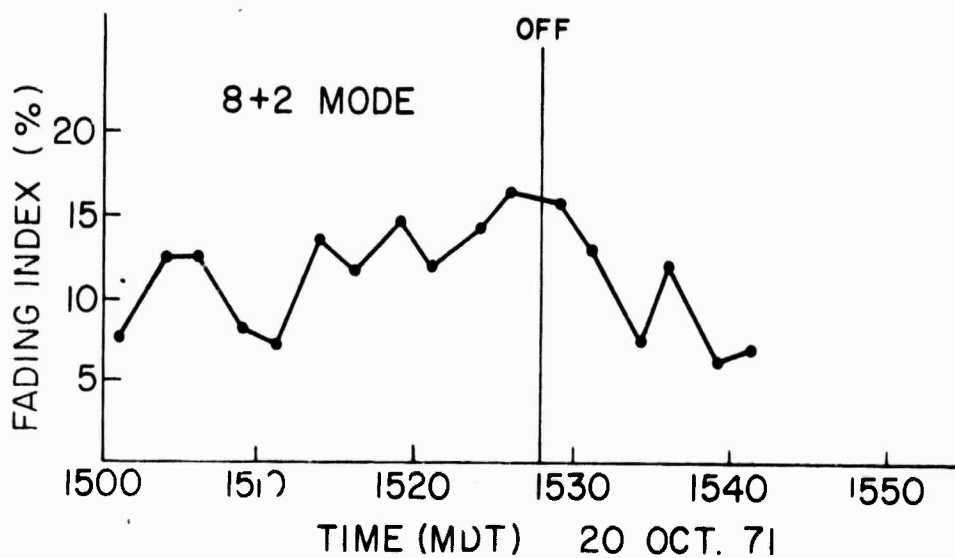
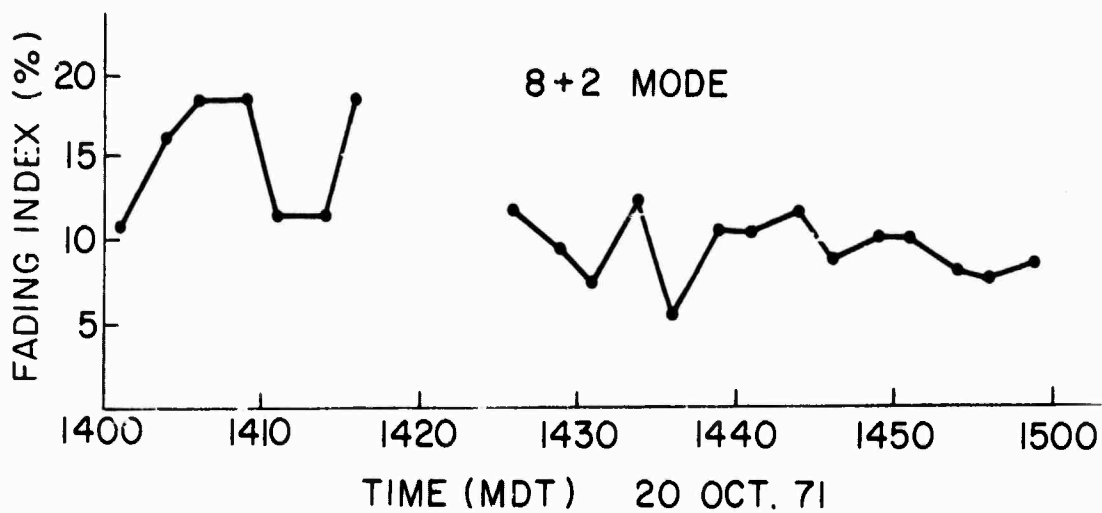
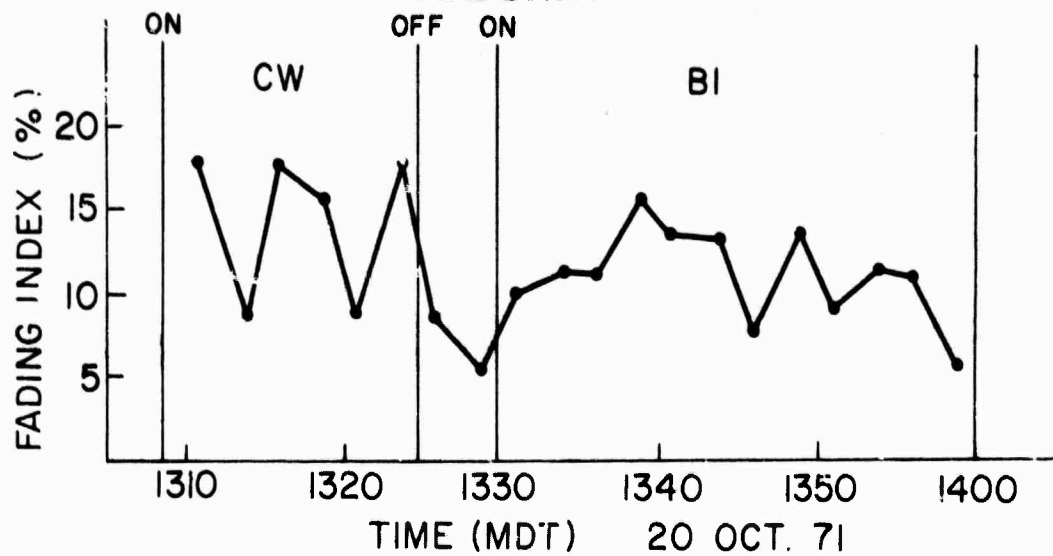


Figure 4.4  
Fading index, 1300-1550 MDT October 20, 1971 (U).

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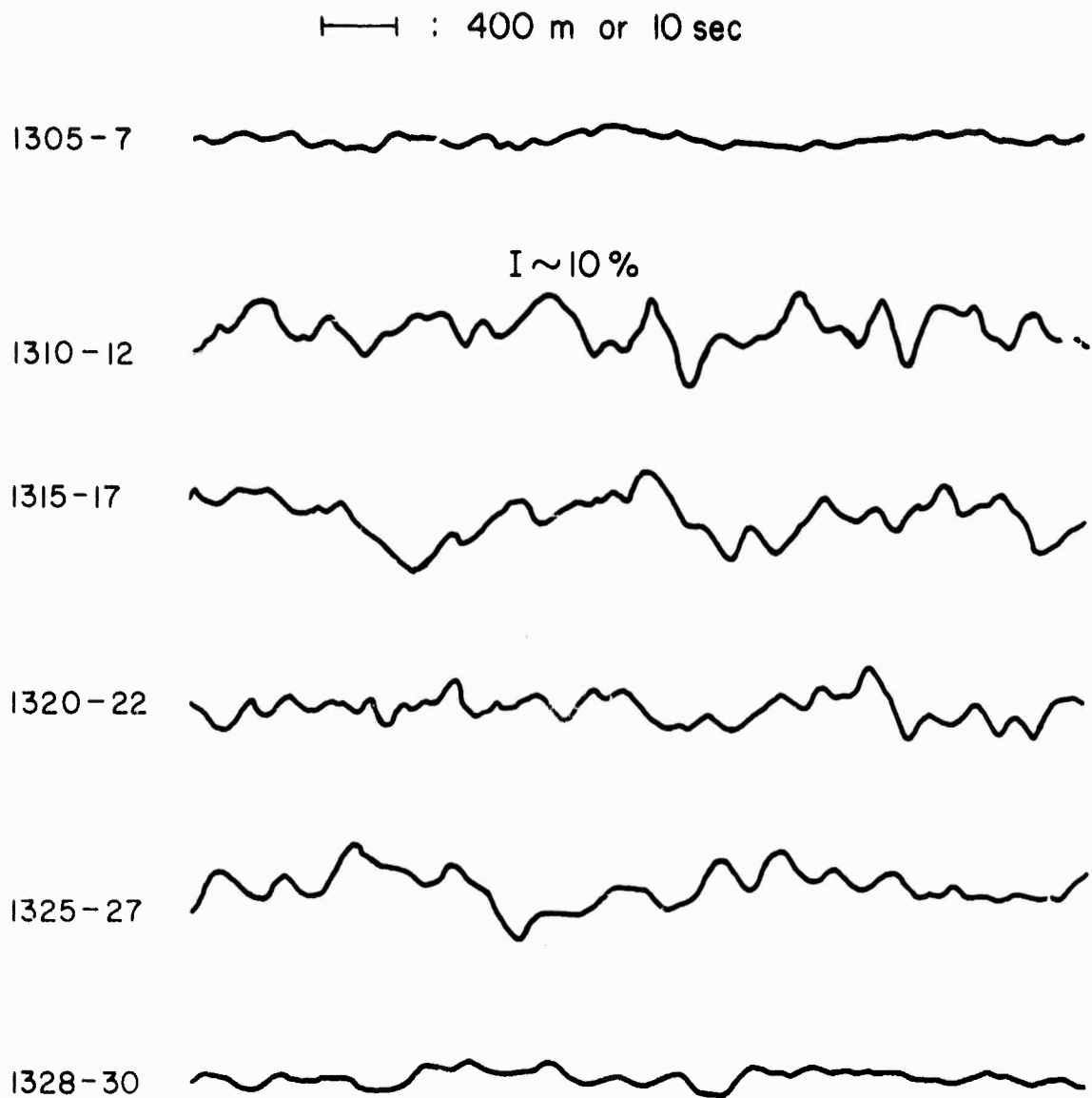


Figure 4.5

Fading, 1305-1330 MDT October 20, 1971 (U).

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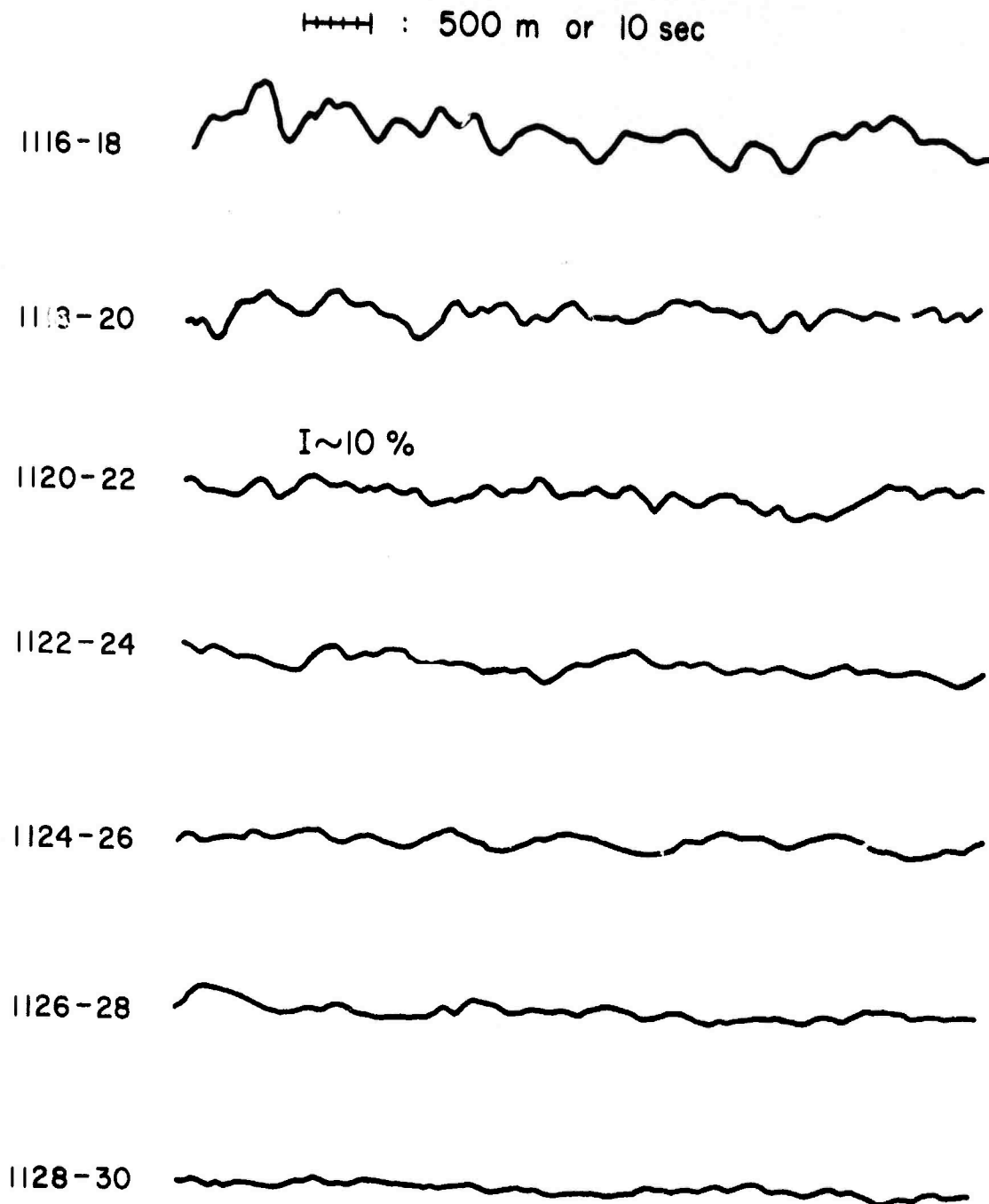


Figure 4.6

Fading, 1116-1120 MDT October 20, 1971 (U).

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shifts for October 19 and 20 are presented on Figures 4.7, 4.8, and 4.9.

(S) Briggs, et al. (1950) were the first to develop a general method of treating moving amplitude diffraction patterns. They assumed that the amplitude pattern on the ground could be represented by a correlation function whose equicorrelation contours form an ellipsoid of revolution in three coordinates, the two spatial coordinates in the ground plane and time.

(S) It has been shown by Sales (1956) and others that provided the pattern observed on the ground is highly elongated and that the component of the drift velocity parallel to the major axis is small compared to the perpendicular component, then the calculation of the pattern orientation and velocity is greatly simplified.

(S) The first condition was satisfied in that an almost perfect time correlation was observed implying a greatly elongated pattern. The second condition will be assumed for the present. Sales shows that under these conditions the locus of points of maximum cross correlation form a straight line known as the line of maxima in nearly the same direction as the major axis of the pattern.

(S) For the antenna spacings used on October 20 the orientation of the line of maxima and the velocity of the pattern are determined by the following relations:

$$\theta = \arctan \left( \left[ \left( t_{13}/t_{12} \right) - 1 \right] \cot \phi \right)$$

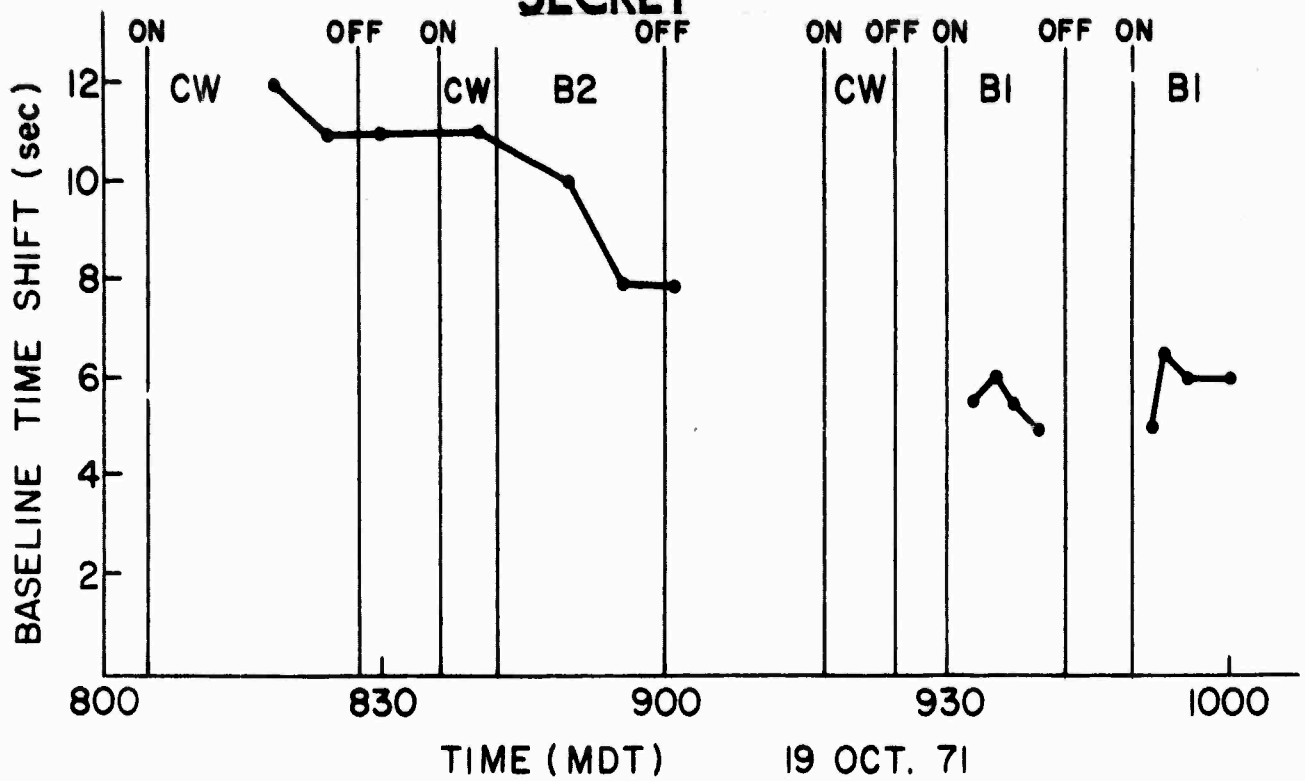
where

$\theta$  = angle north of east for easterly motion between the perpendicular to the line of maxima and the east-west baseline,

$t_{12}$  = time shift representing maximum cross correlation between the east and west antennas,

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BASELINE = 300 m

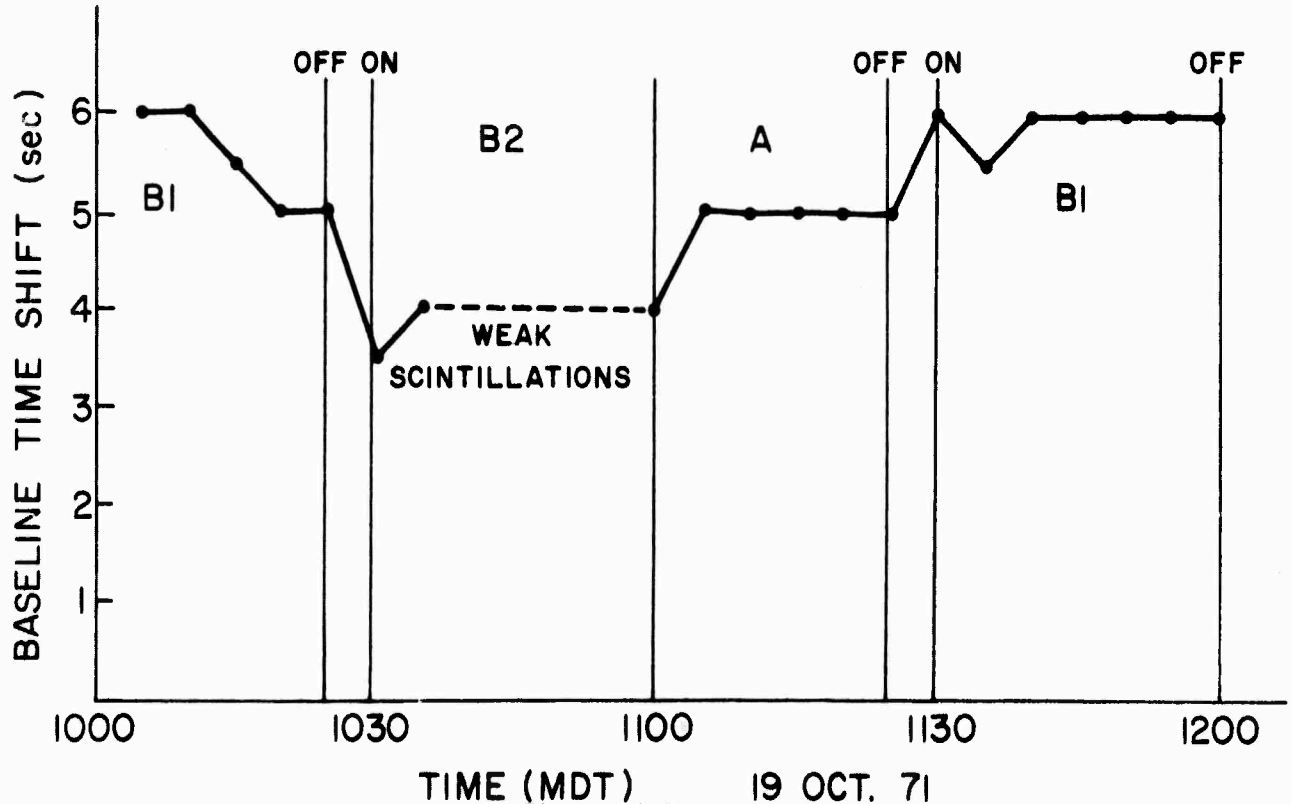


Figure 4.7  
Baseline time shift, 0800-1200 MDT October 19, 1971 (U).

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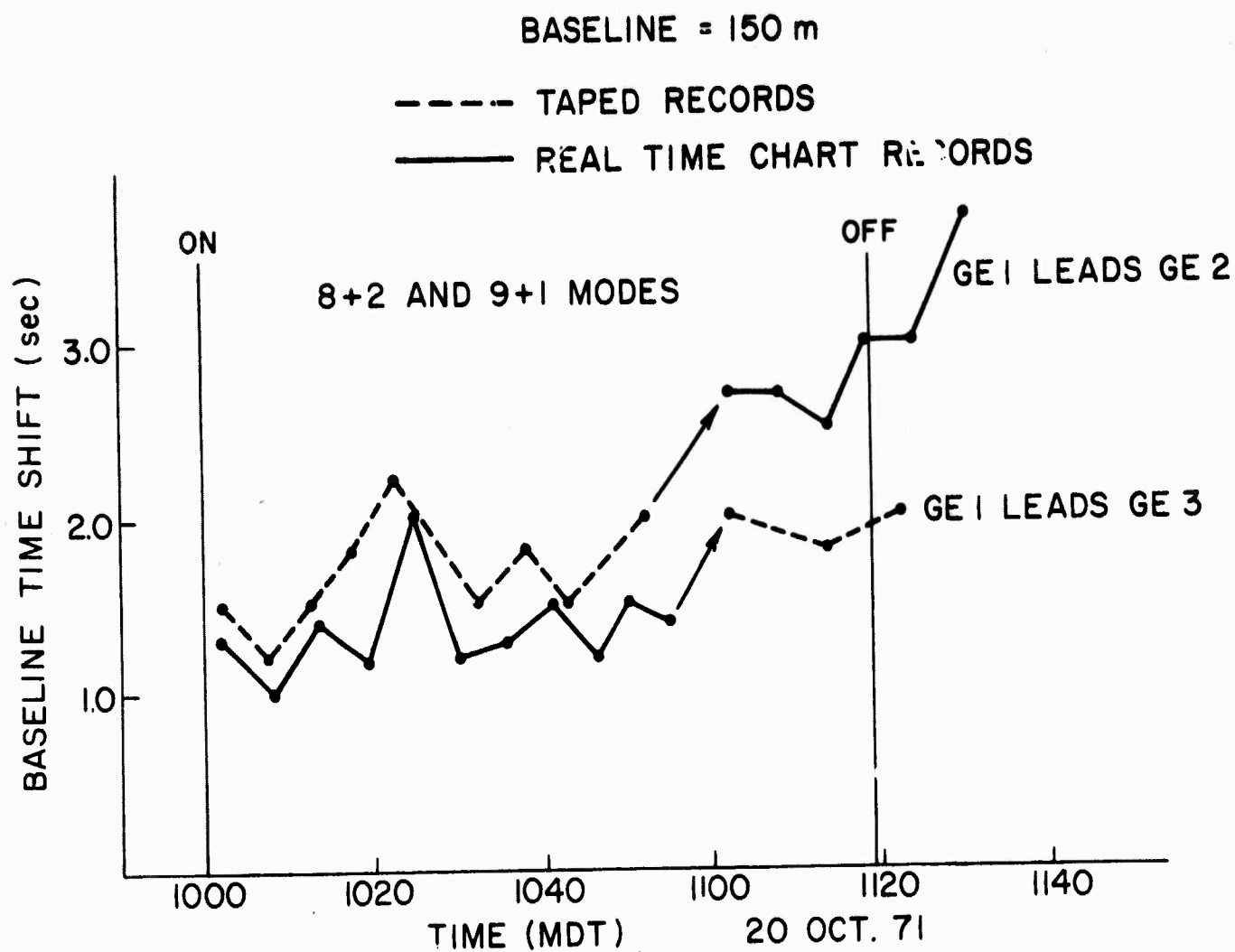


Figure 4.8

Baseline time shift, 1000-1140 MDT October 20, 1971 (U).

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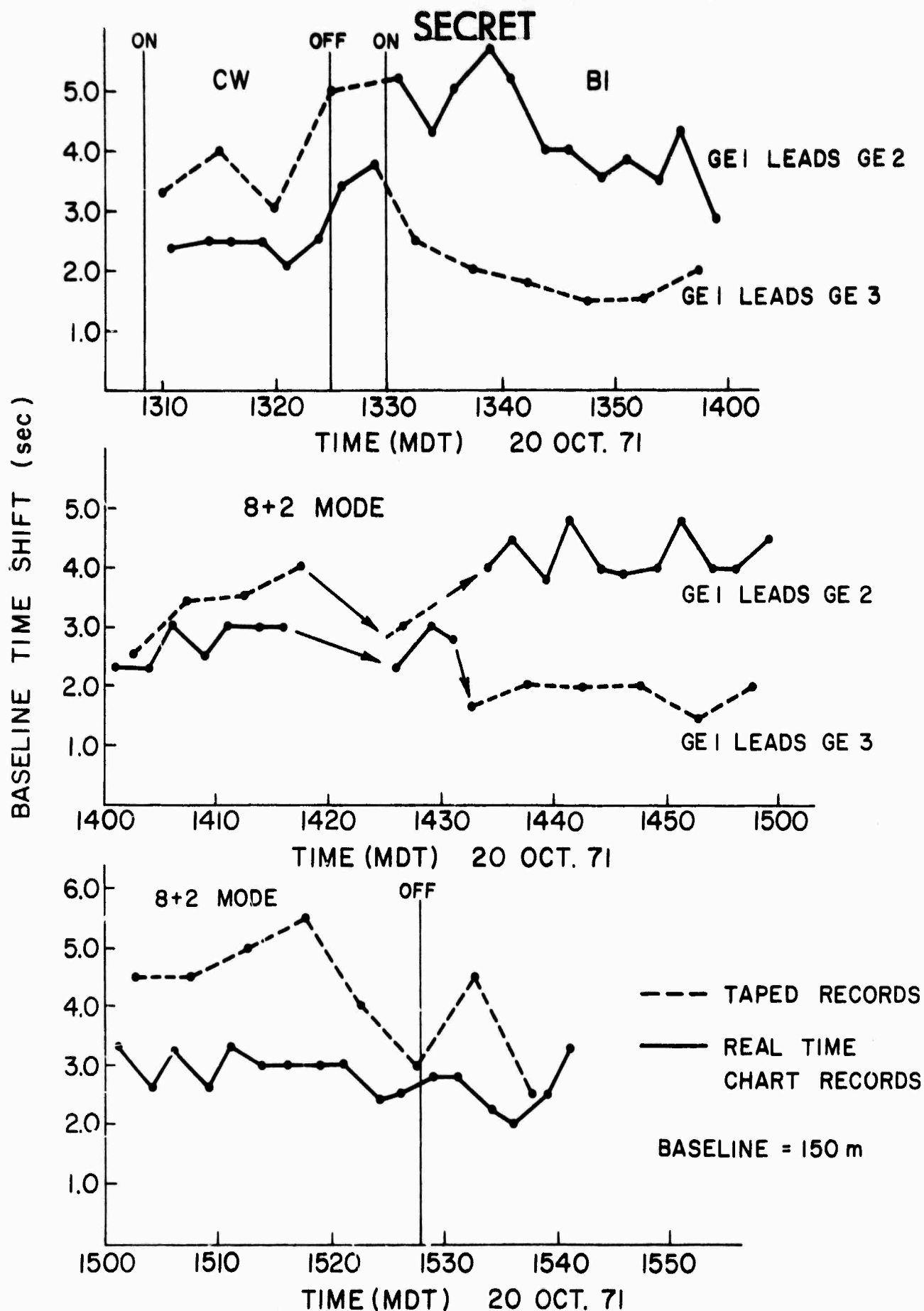


Figure 4.9

Baseline time shift, 1310-1550 MDT October 20, 1971 (U).

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$\tau_{13}$  = time shift representing maximum cross correlation between the west and north antennas,

$\phi$  = base angle of isosceles triangle which the antennas form.

$$V = L \cos \theta / t_{12}$$

where

$V$  = pattern velocity component perpendicular to the line of maxima,

$L$  = east-west antenna separation.

Values for the velocity based on the time shifts observed on October 20 are shown in Figures 4.10, 4.11, and 4.12, and the corresponding directions of the lines of maxima for October 20 are given in Figure 4.13. The velocities are to be interpreted as being resolved in a direction normal to the line of maxima, and consistently in a west-to-east direction.

(S) The average fading period is defined simply as the number of maxima in a given stretch of record divided into its duration. For a Gaussian autocorrelation function, this is just 3.63 times the time separation required to give an autocorrelation of  $\exp(-1/2)$ , or 0.61. Since the fading pattern appears to move over the receiving antennas without change of form, one may use the observed velocity to deduce a separation period, or average structure size, transverse to the line of maxima, simply by multiplying the deduced velocity by the average fading period. The results of this calculation are presented in Figures 4.14 and 4.15 for October 19 and 20, respectively.

(S) Velocities and structure size for October 19 (only two antennas being available) were deduced on the assumption that the line of maxima was nearly in the north-south direction (as it was on October 20).

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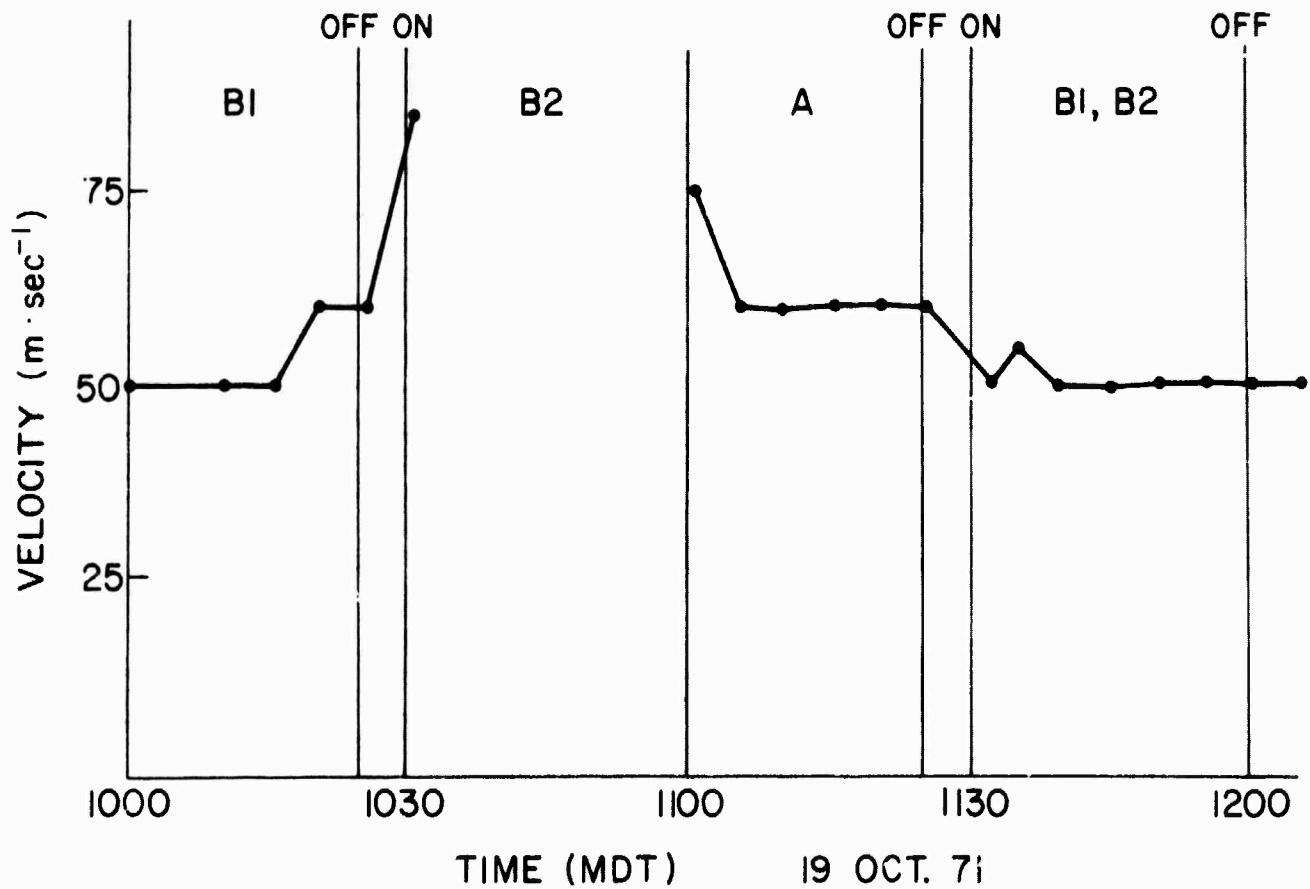
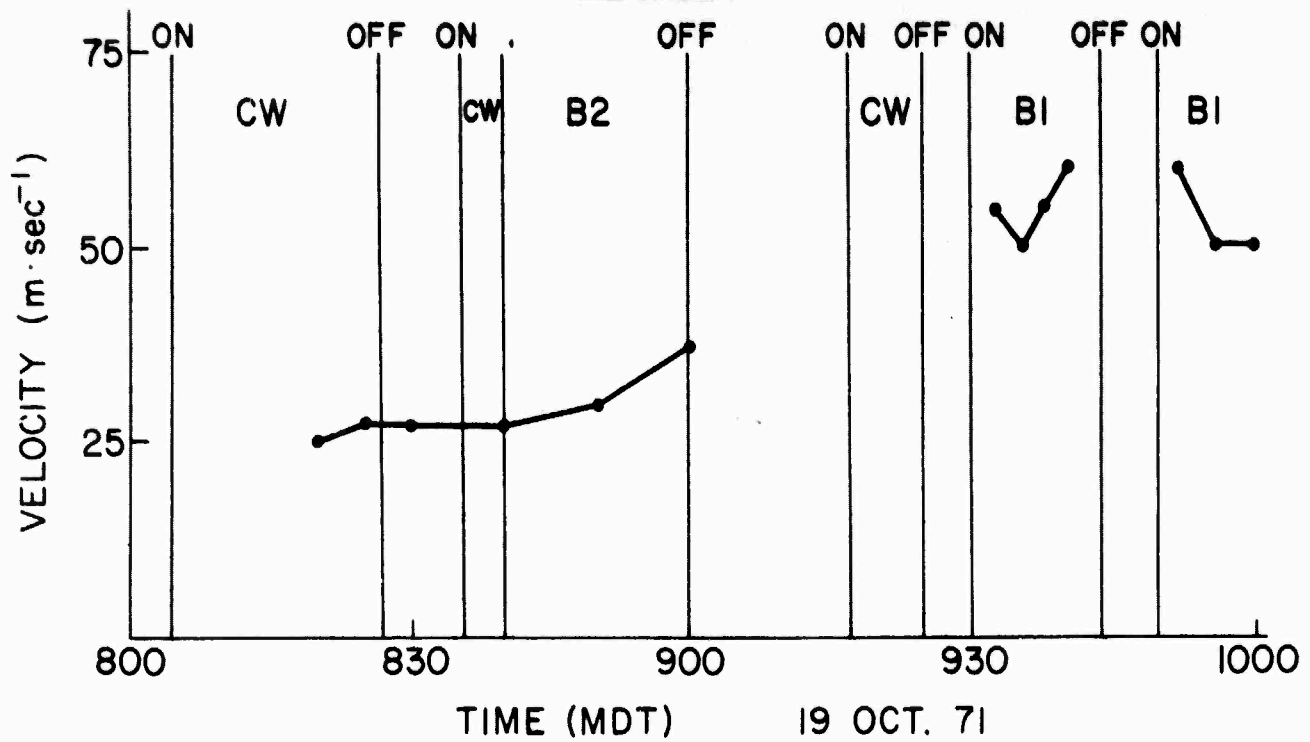


Figure 4.10  
Velocity, 0800-1205 MDT October 19, 1971 (U).

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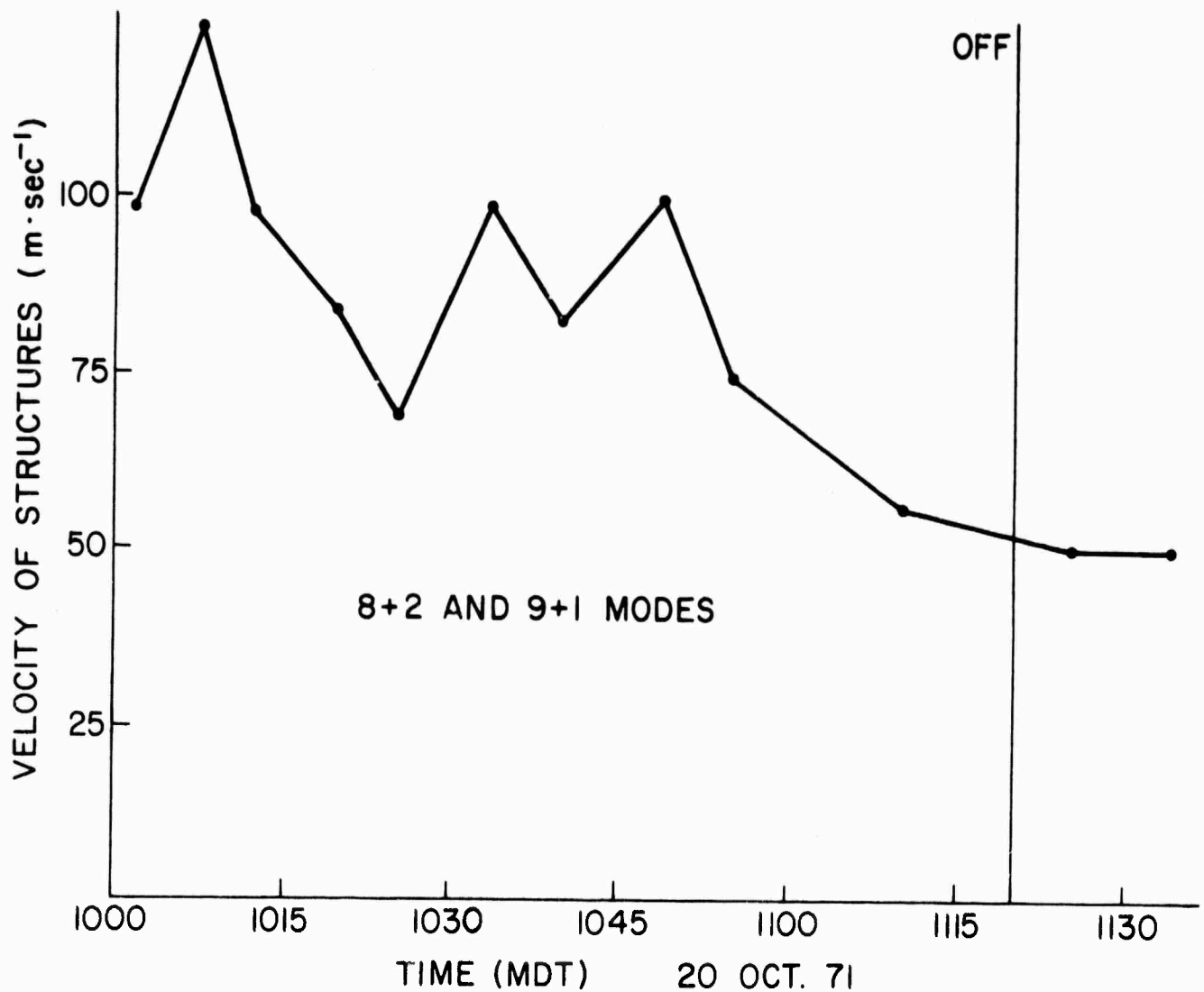


Figure 4.11

Velocity, 1000-1135 MDT October 20, 1971 (U).

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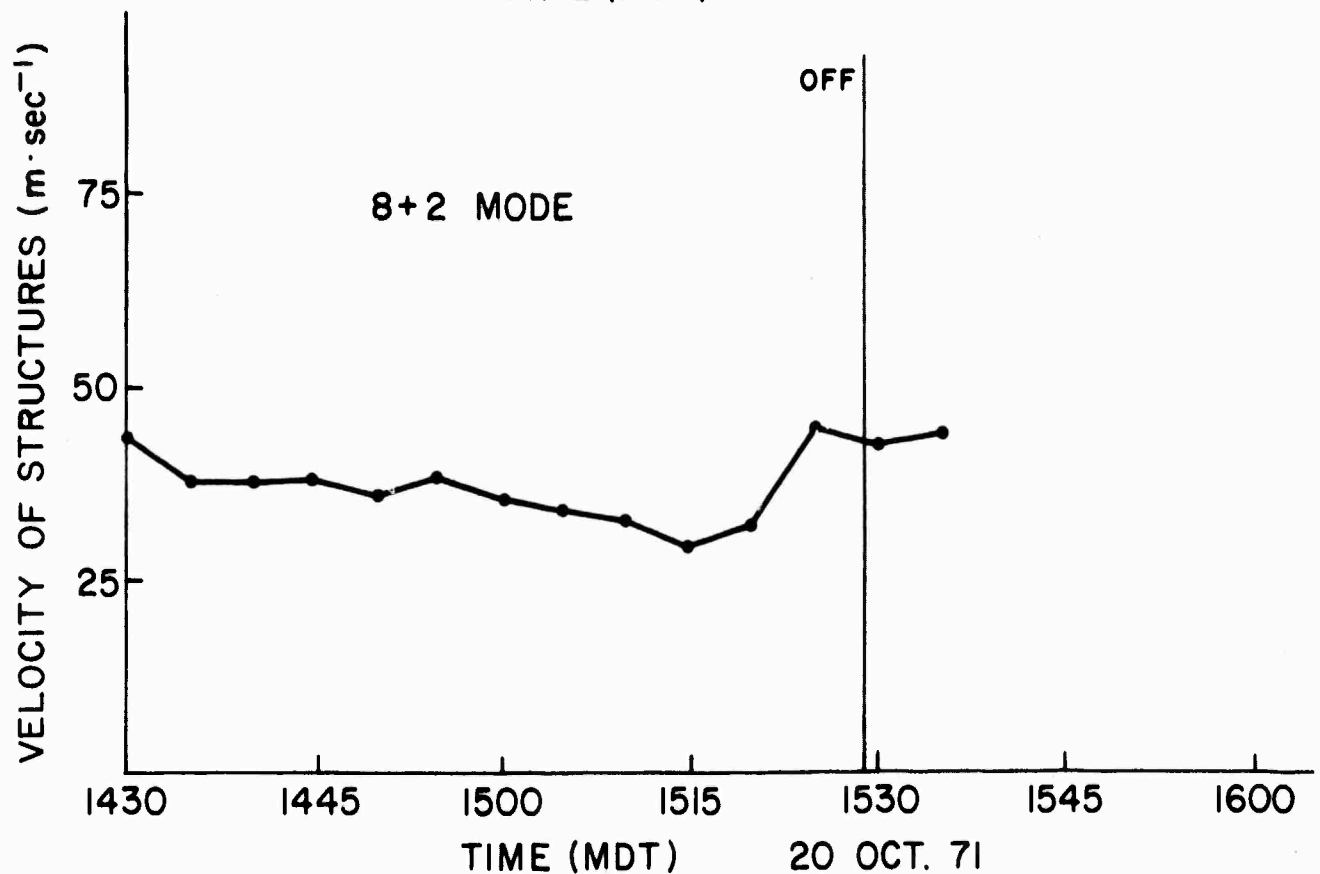
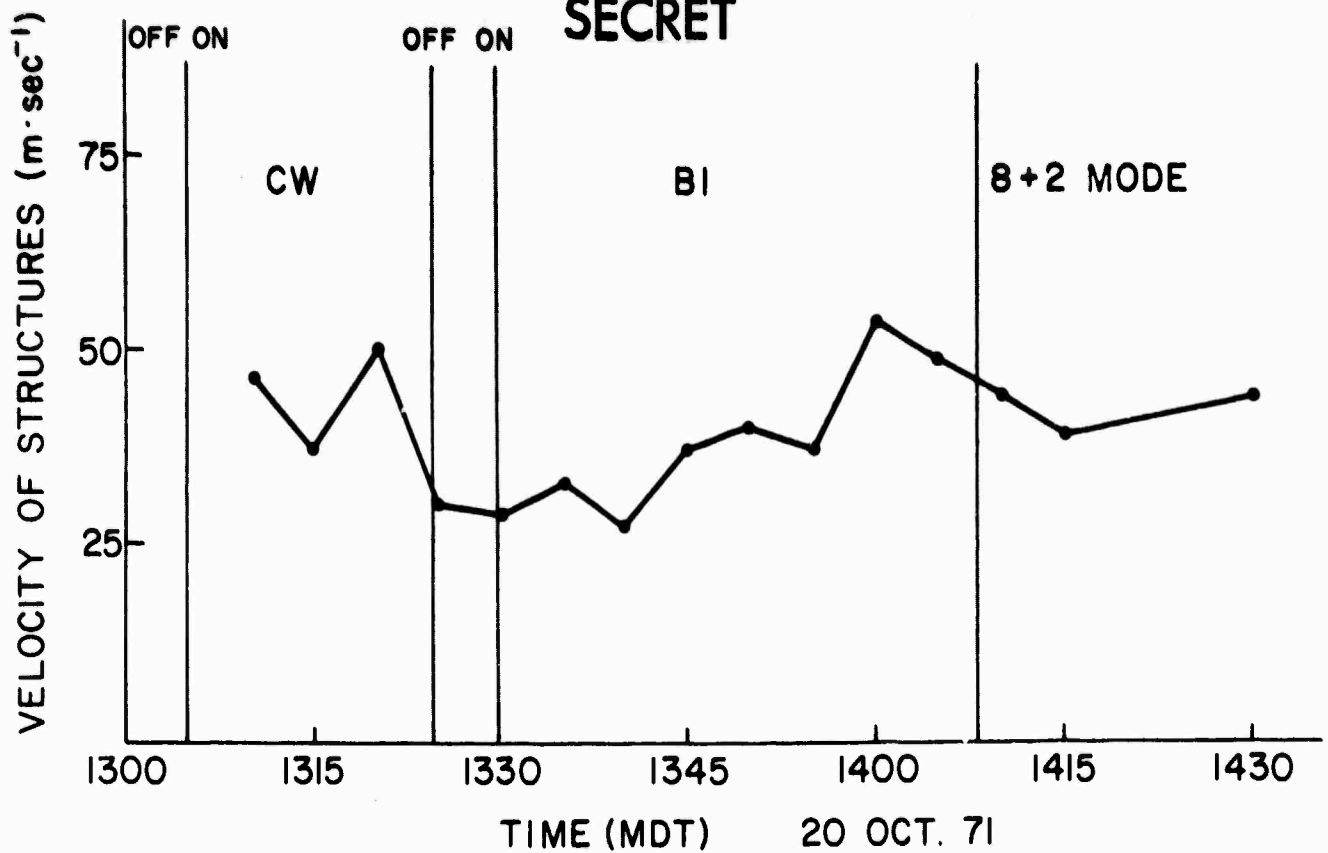


Figure 4.12  
Velocity, 1300-1540 MDT October 20, 1971 (U).

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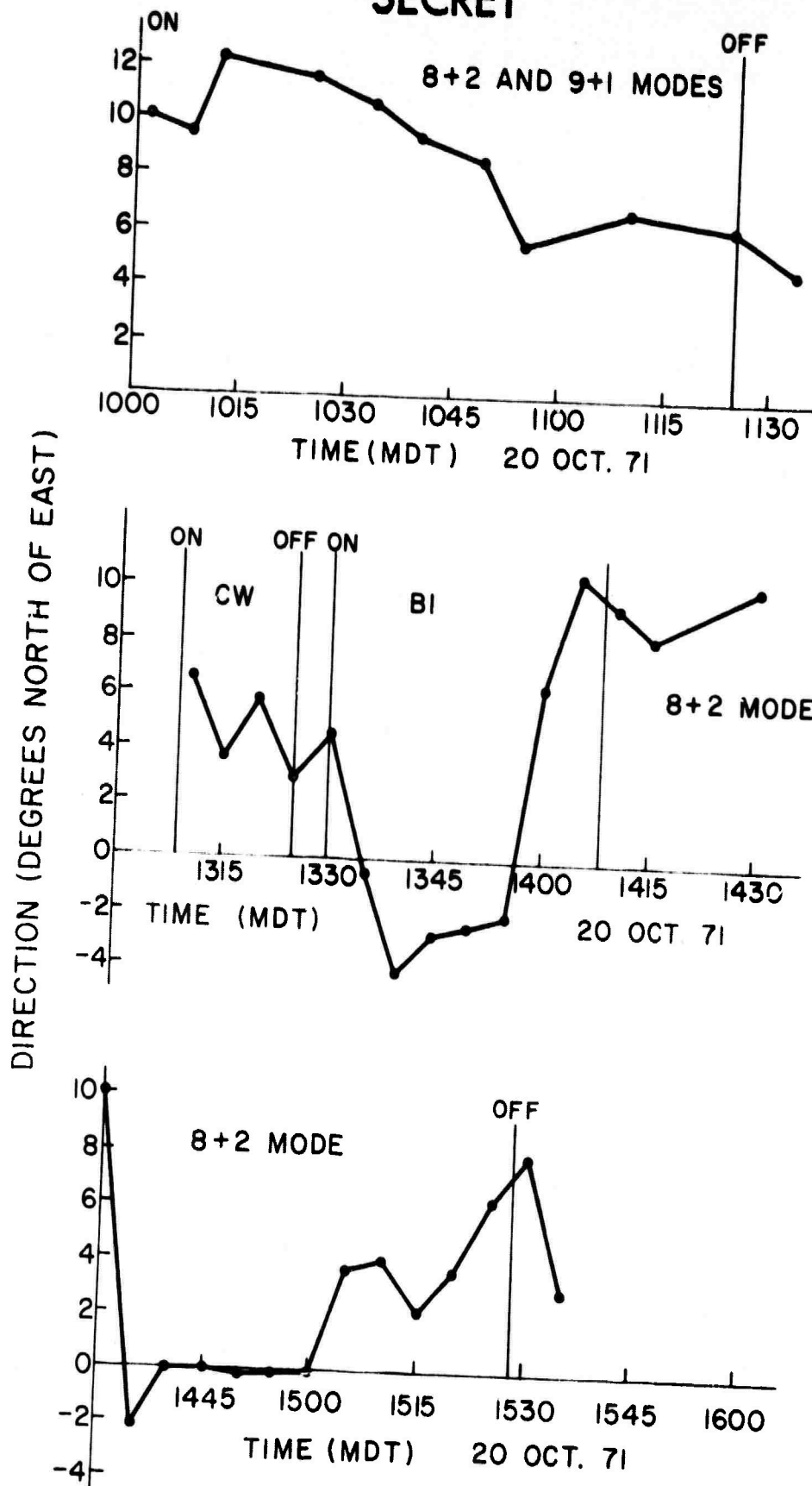


Figure 4.13  
Striation direction, 1000-1540 MDT October 20, 1971 (U).

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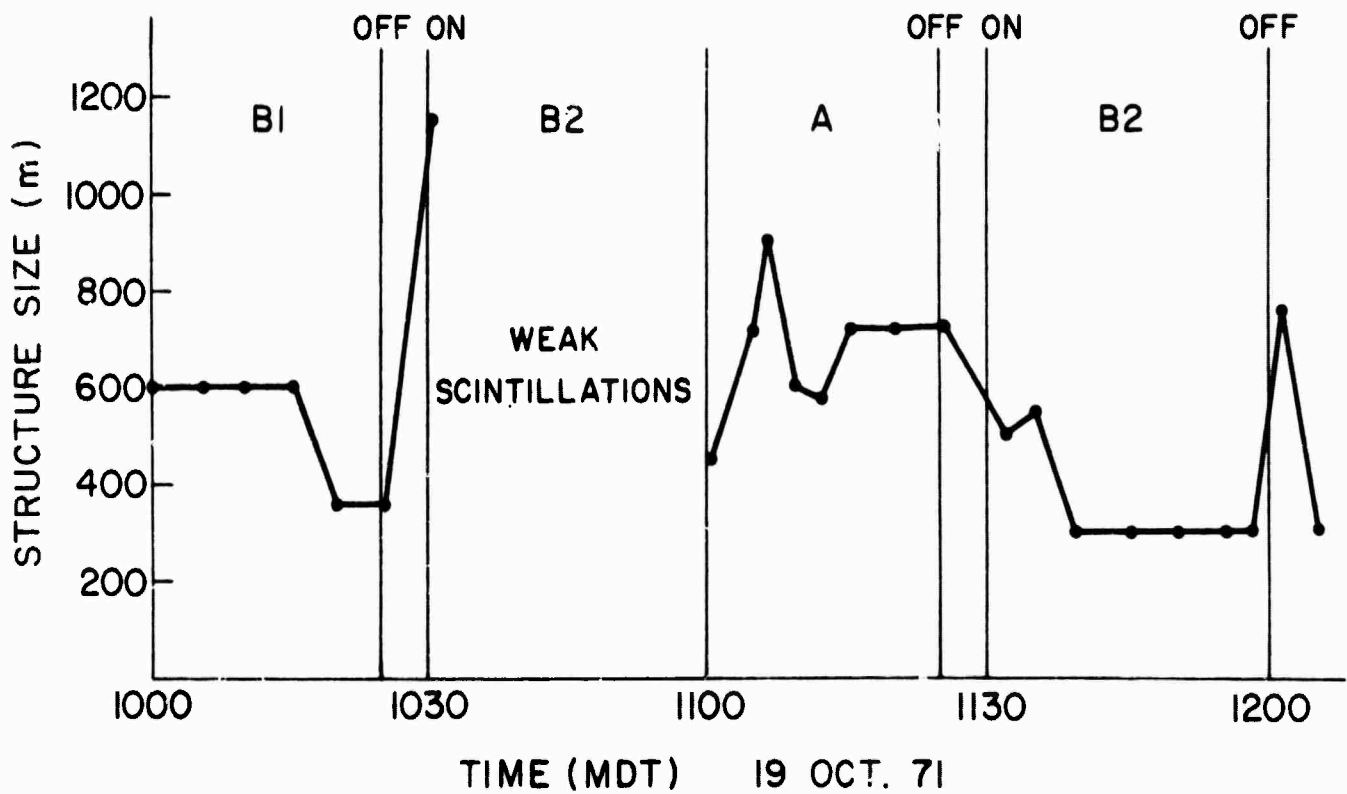
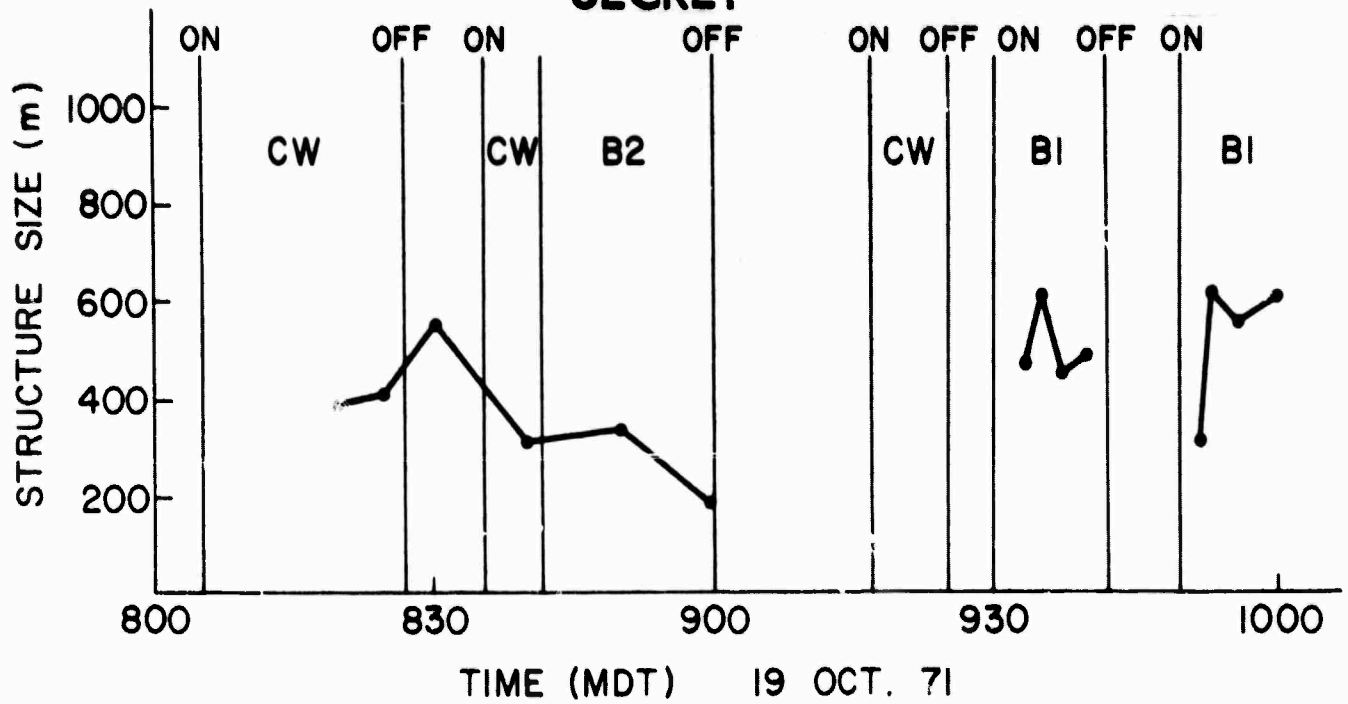


Figure 4.14

Striation size, 0800-1205 MDT October 19, 1971 (U).

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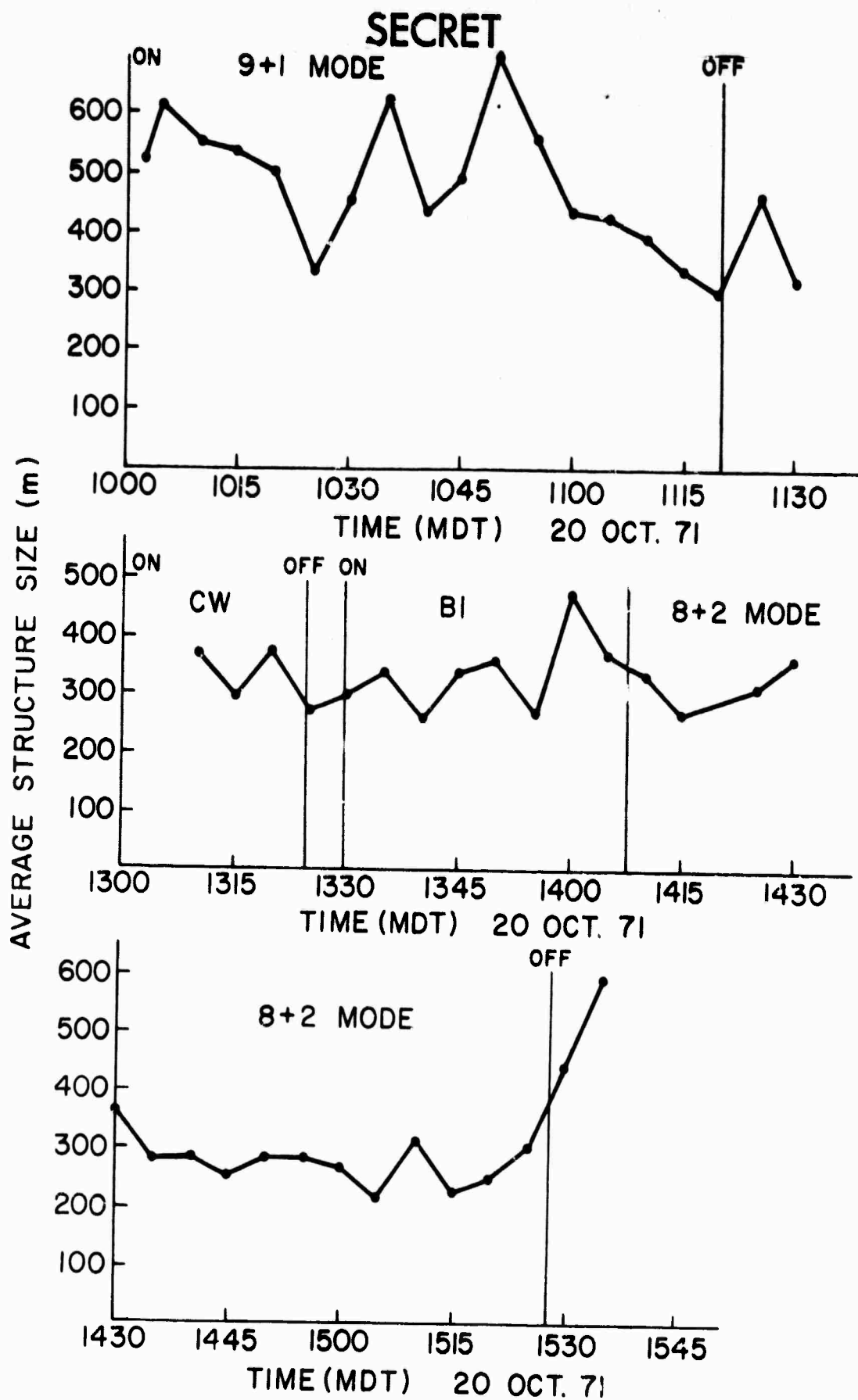


Figure 4.15  
Striation size, 1000-1540 MDT October 20, 1971 (U).

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## 5. RESULTS OF ORBITAL EXPERIMENT (U)

(S) The satellites of the US Navy Satellite Navigation System are all in approximately circular polar orbits at heights of about 1000 km above the earth's surface. Since their times of passage are distributed (though somewhat irregularly) throughout the day, they are particularly suitable for transmission studies of specific regions of the ionosphere such as that over Platteville. Unfortunately, only one or two a day pass sufficiently near overhead to permit their use as a consistent diagnostic for a fixed station, and these may not be suitable times on any given day. However, on December 6, 1971 the pass described in Table 3.1 and Figure 3.2 took place, the satellite passing within  $5^\circ$  of overhead and very close to the magnetic field line above the receiving station.

(S) Figures 5.1 and 5.2 show the behavior of the fading intensity and the average fading period as a function of the elevation angle of the satellite. Also shown is the distance north of the heater transmitter at which the satellite direction intersects the 300-km-height sphere.

(S) The severe fading occurring at about  $70-73^\circ$  elevation angle is illustrated on the fading records of Figures 5.3 and 5.4. Several different periods of fading are evident, some evidently limited by the detector time constant of 10 m sec. A 3-m sec time constant (Figures 5.5 and 5.6) show a somewhat greater fading, and the presence of very short periods; this is confirmed by a careful inspection of recordings made of faster chart speeds. Much earlier than these records, a very pronounced fading was seen at the two antennas separated by 40 m in the east-west direction (Figure 5.7). Examination of these with a faster chart speed (Figures 5.8 and 5.9) shows that a consistent time shift is present, the east antenna preceding the west antenna by about 0.12 sec.

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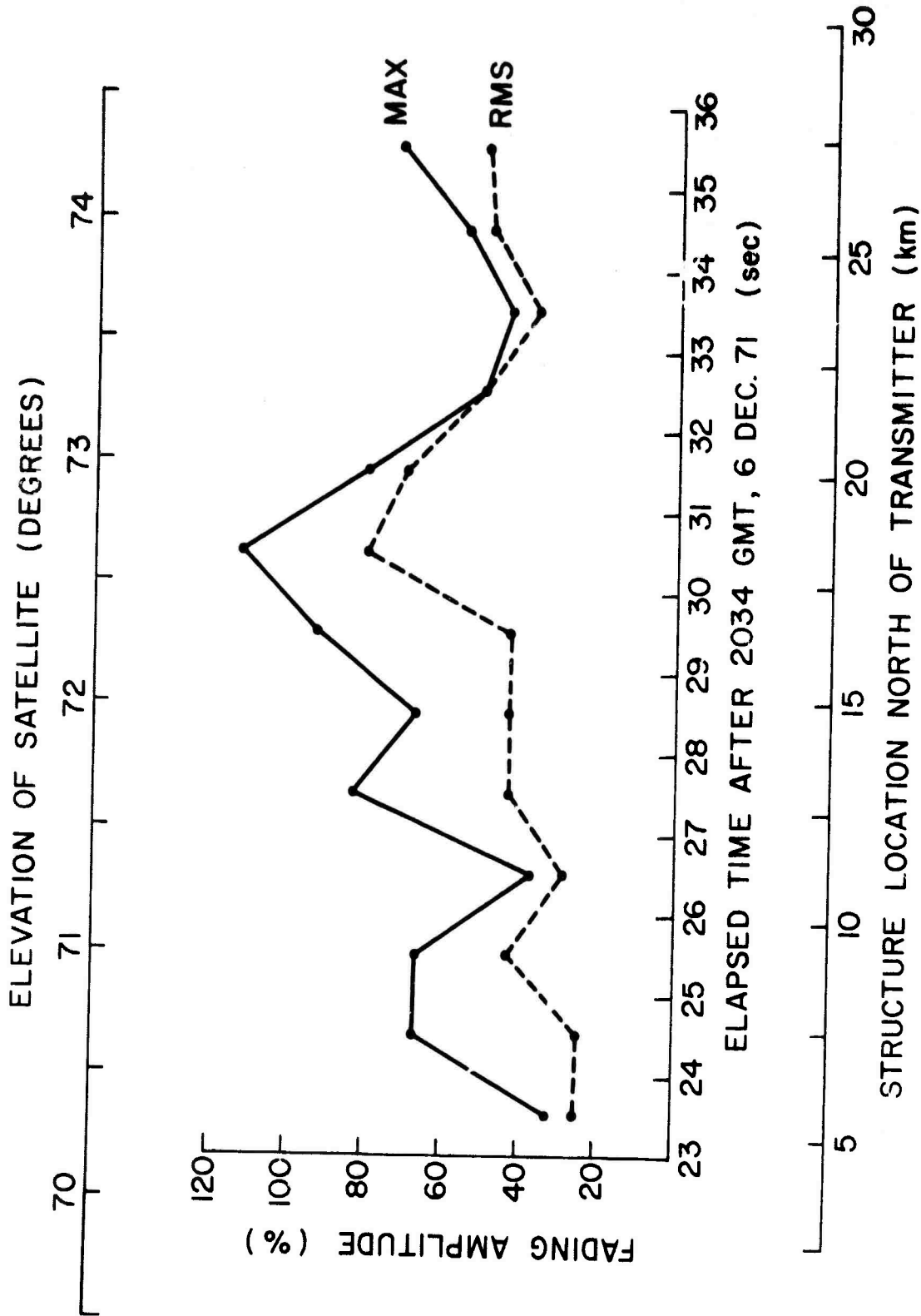


Figure 5.1

Orbital fading index, December 6, 1971 (U).

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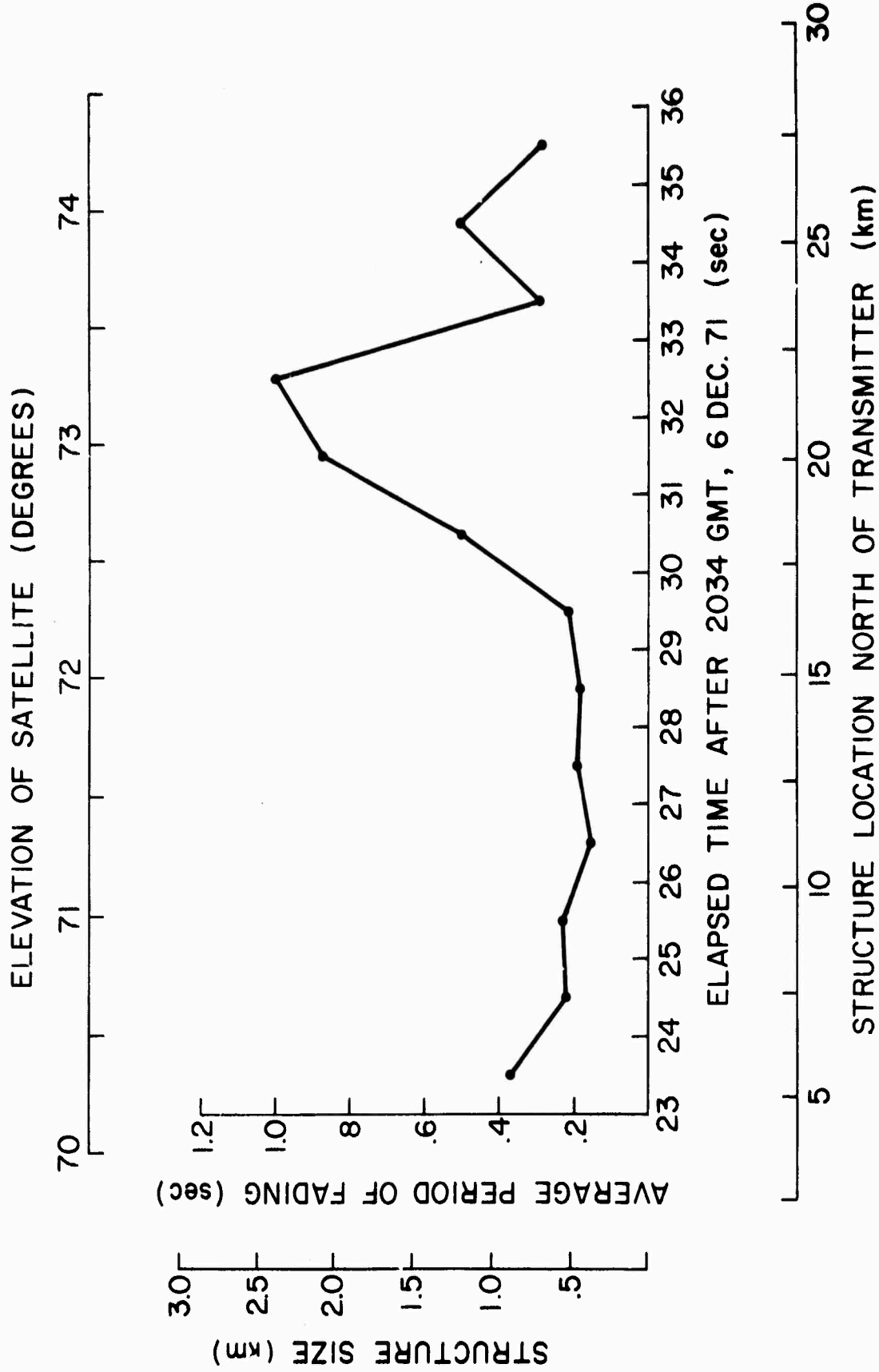


Figure 5.2

Orbital fading period, December 6, 1971 (U).

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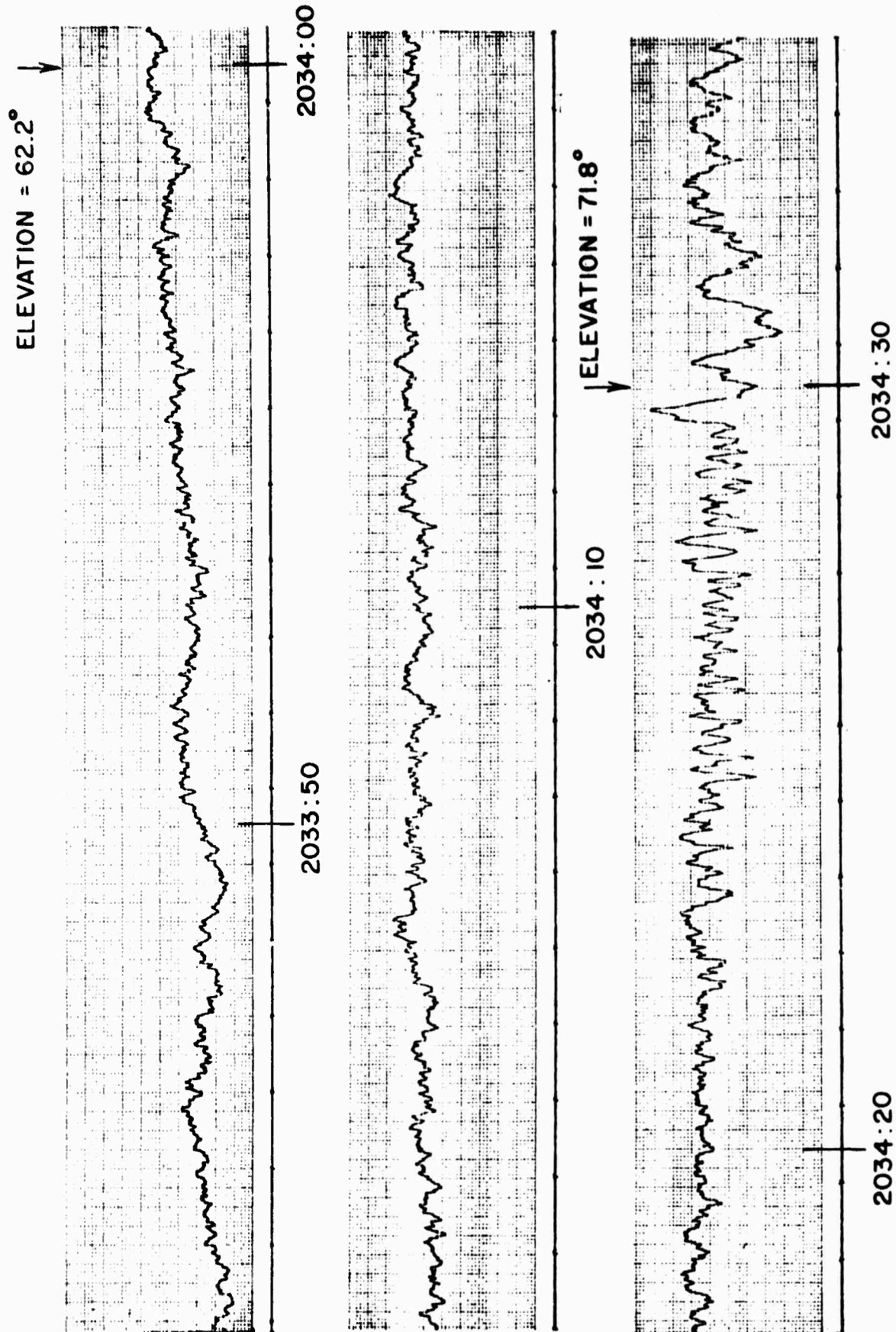


Figure 5.3  
Orbital fading, December 6, 1971 (U).

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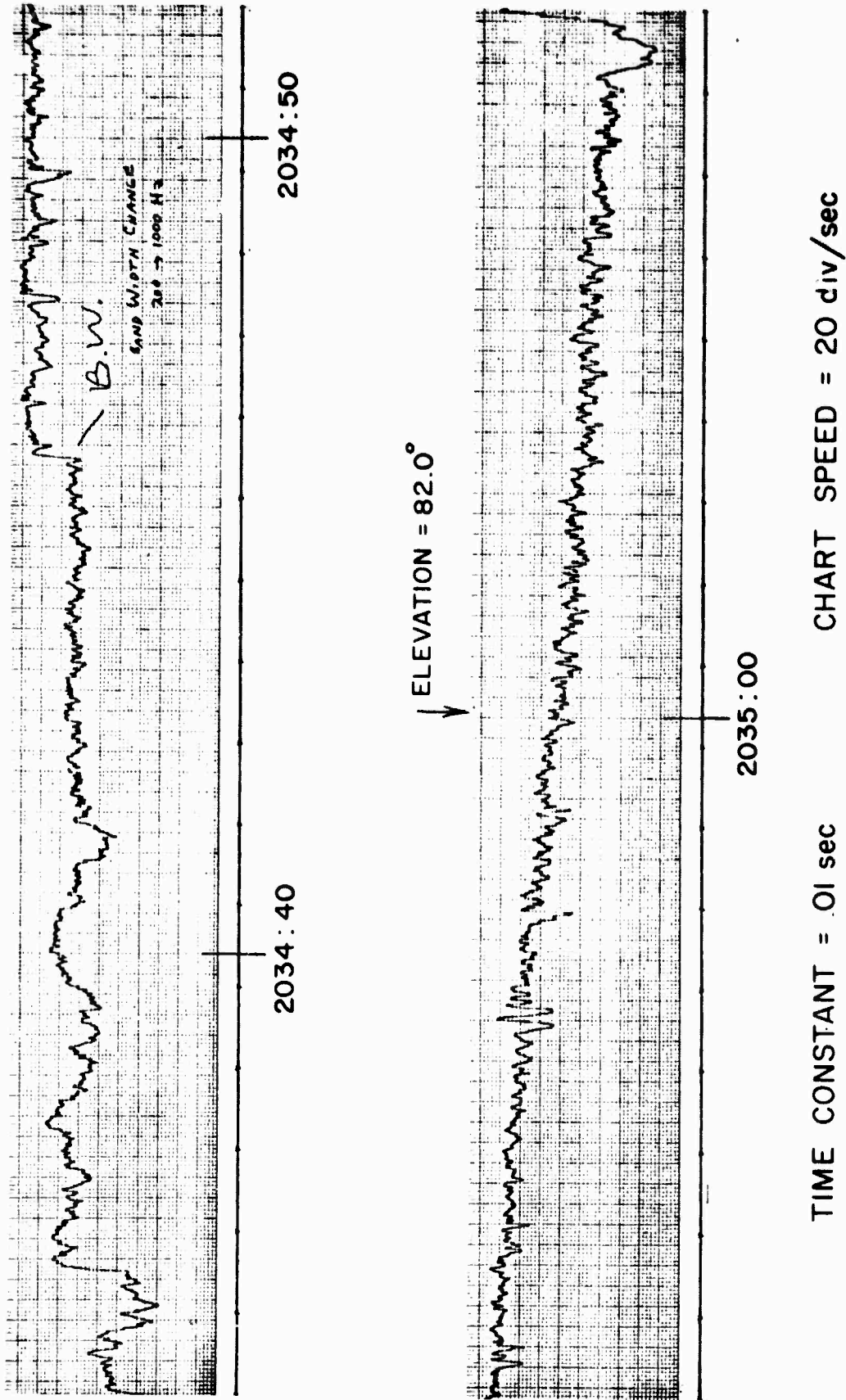


Figure 5.4

Orbital fading, December 6, 1971 continued (U).

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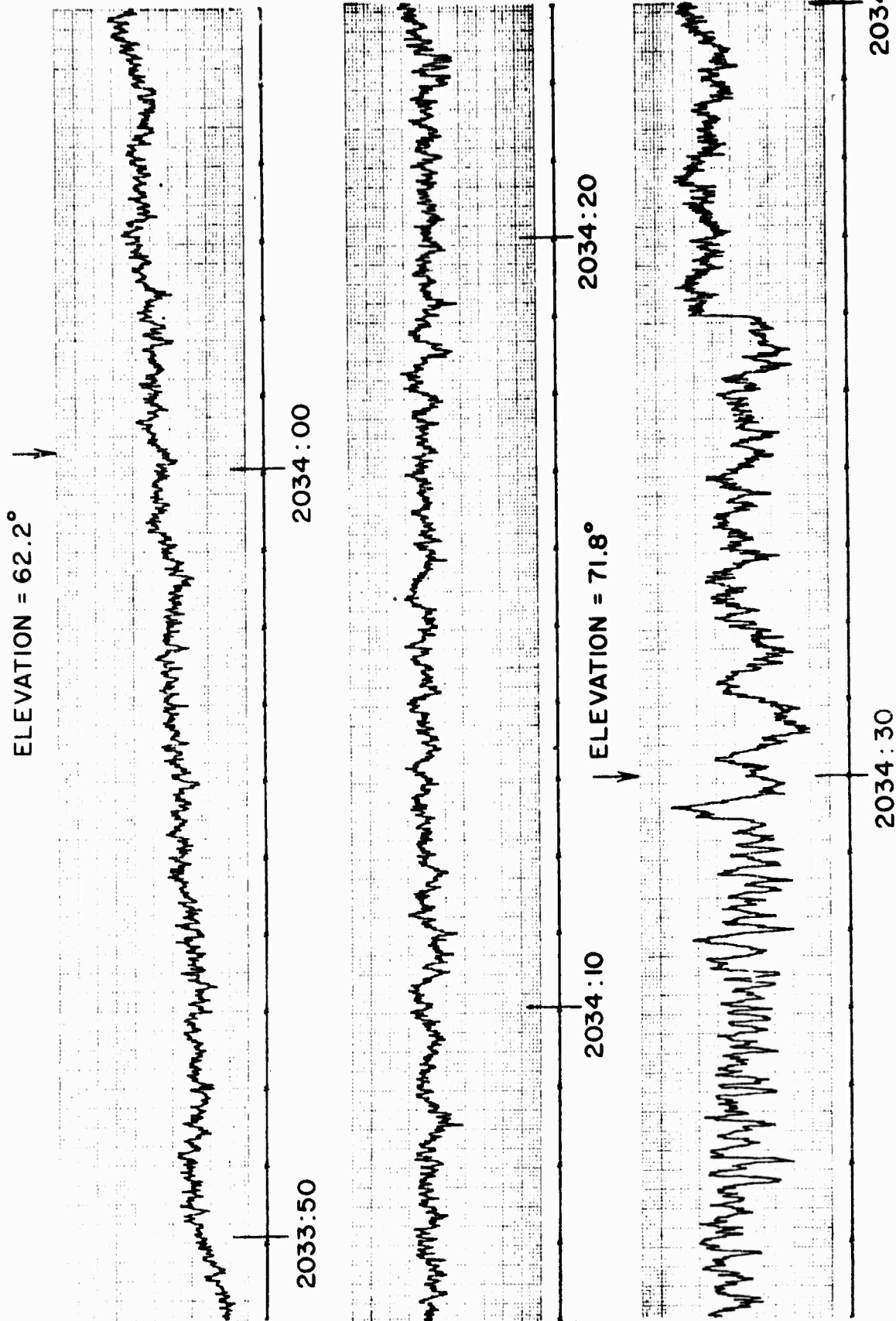
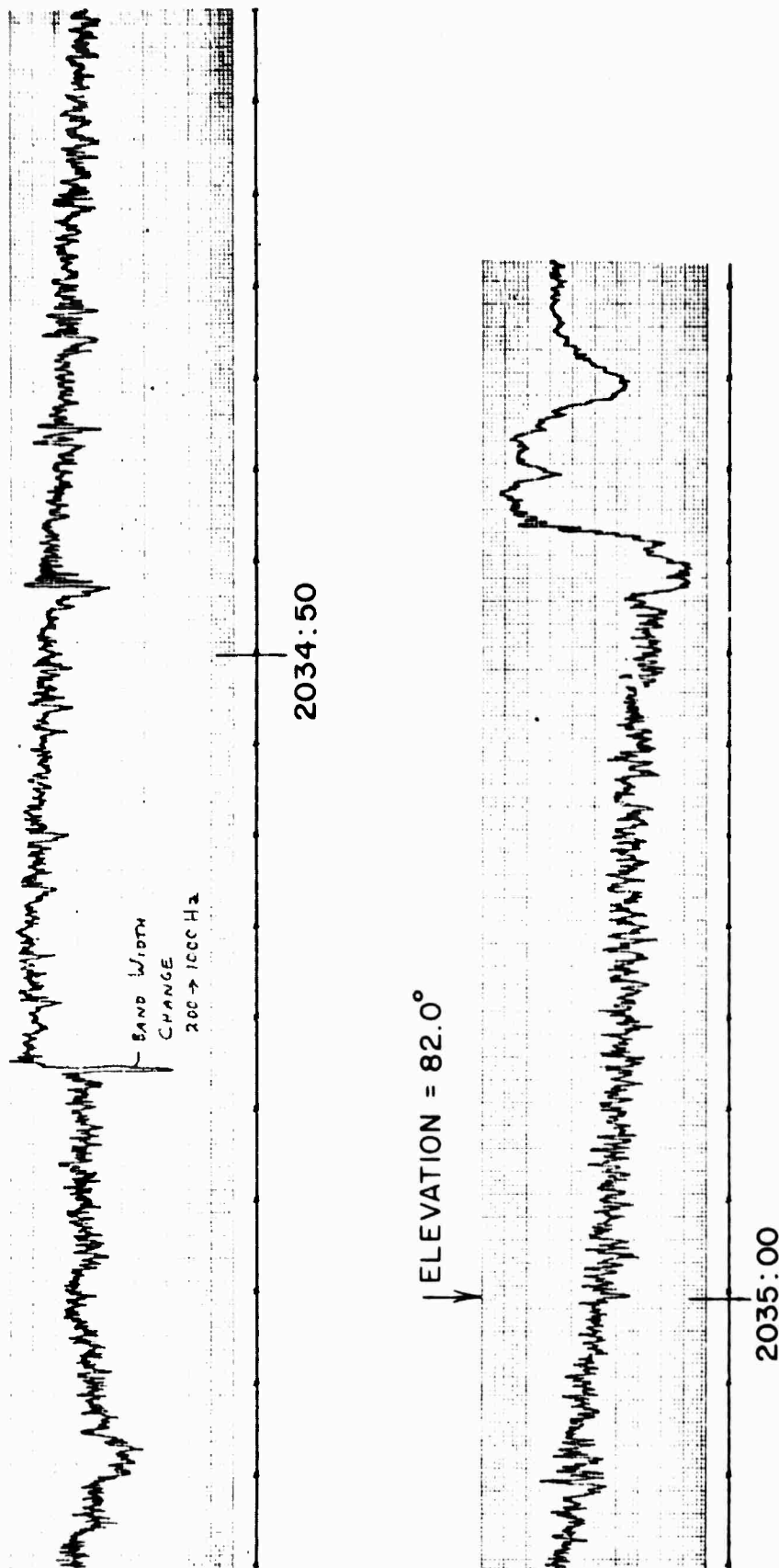


Figure 5.5  
Orbital fading (short time constant) (U).

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TIME CONSTANT =  $3.3 \times 10^{-3}$  sec      CHART SPEED = 20 div/sec

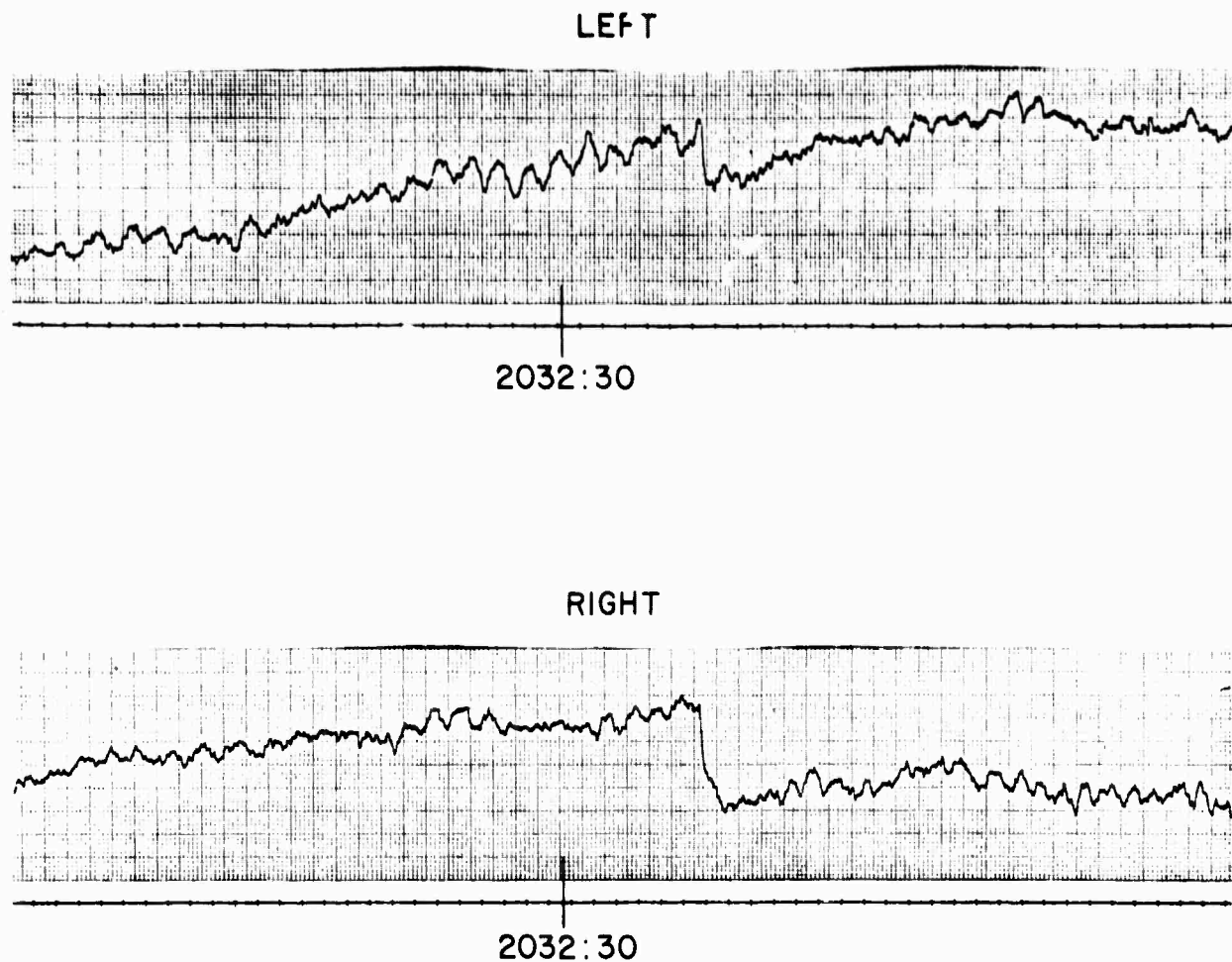
GMT, 6 DEC. 71

Figure 5.6

Orbital fading (short time constant) continued (U).



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TIME CONSTANT = .03 sec

CHART SPEED = 5 div/sec

GMT, 6 DEC. 71

SATELLITE ELEVATIONS : 32.8° AT 2032:00

38.8° AT 2032:30

45.8° AT 2033:00

Figure 5.7  
Orbital fading at spaced antennas (U).

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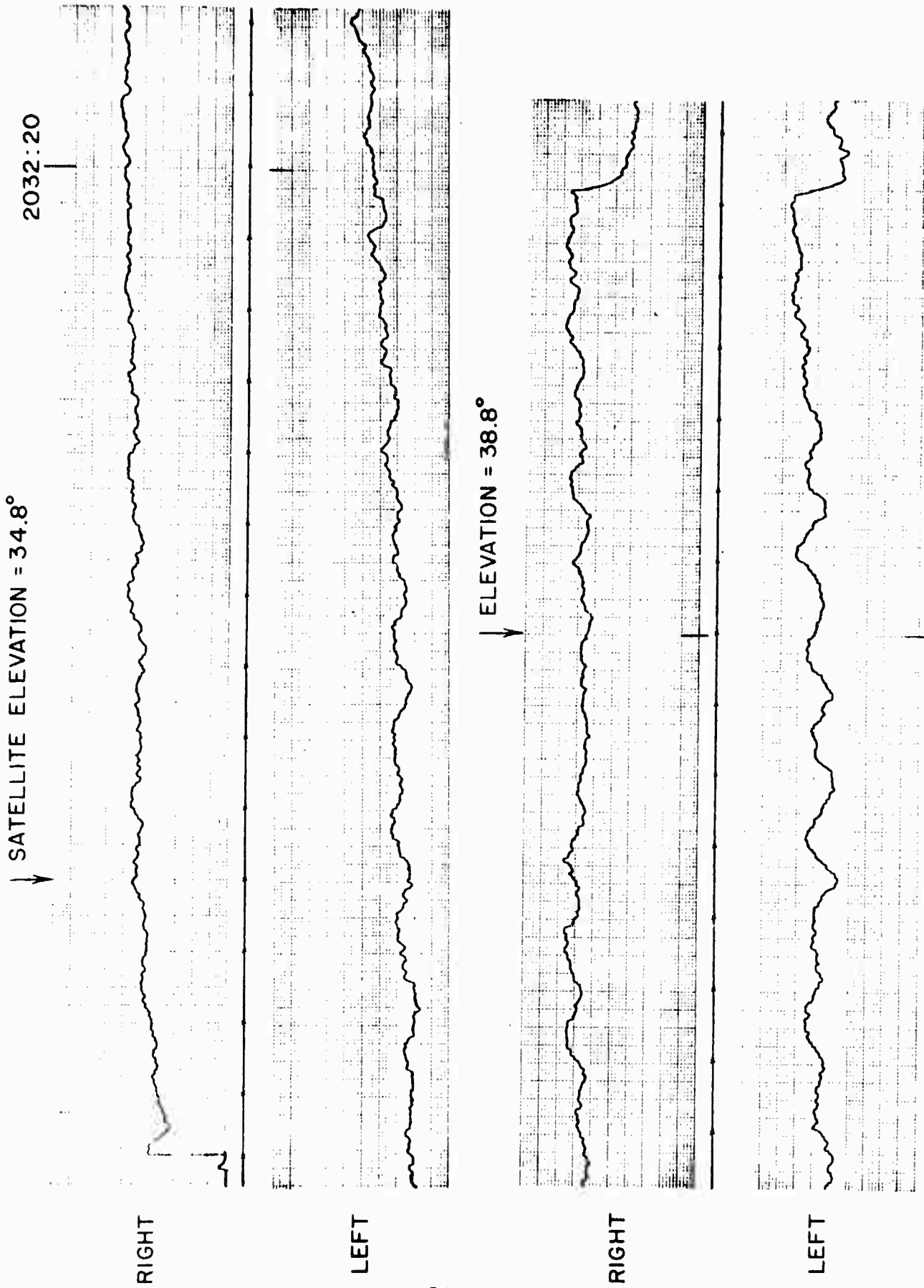
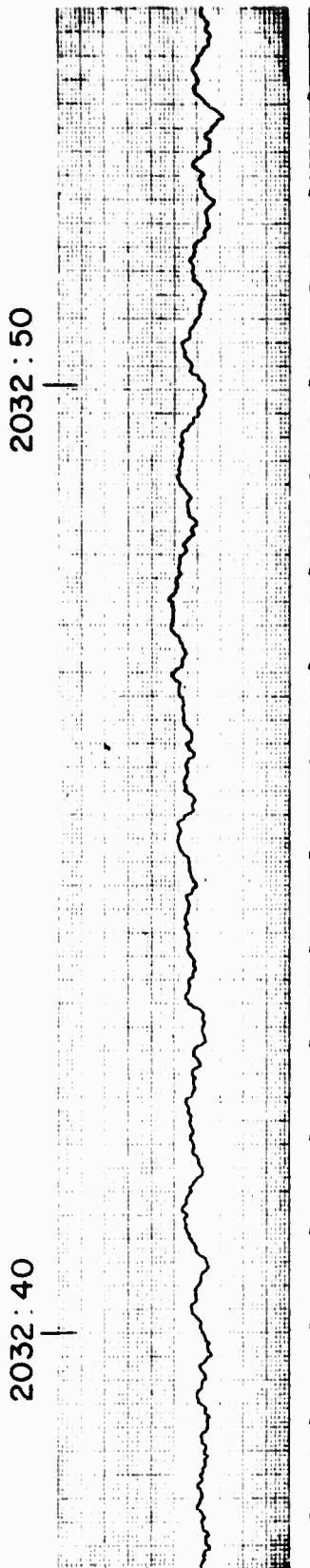


Figure 5.8  
Orbital fading at spaced antennas (high speed) (U).

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ELEVATION =  $43.35^\circ$  ↓  
2032:40      2032:50



RIGHT



LEFT  
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TIME CONSTANT = .03 sec      CHART SPEED = 20 div/sec

GMT, 6 DEC. 71

RIGHT CHANNEL = EAST ANTENNA

LEFT CHANNEL = WEST ANTENNA

BASELINE SEPARATION = 135 feet

Figure 5.9

Orbital fading at spaced antennas (high speed) continued (U).

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(S) The scope of the measurements during Prairie Smoke Ib on February 14-17, 1972, is indicated in Table 5.1. Sections of record (to the same time scale as Figure 5.3) showing the general nature of the deepest fading seen at the four sites is shown in Figure 5.10.

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Table 5.1

DATE 1972	RRI OBSERVATION MST	OBSERVATION LOCATION	LOS OVER TRANSMITTER		
			TIME MST	RANGE km	NUMBER OF ANTENNAS
14 FEB.	0830-1300	SINCLAIR, WYO.	1337:00	1360	2
15 FEB.	1500-1942	KIMBALL, NEB.	1449:57	1215	2
16 FEB.	1500-1947	BUFORD, WYO.	1901:40	1185	3
17 FEB.	1500-2000	RED DESERT, WYO.	1745:50	1365	2

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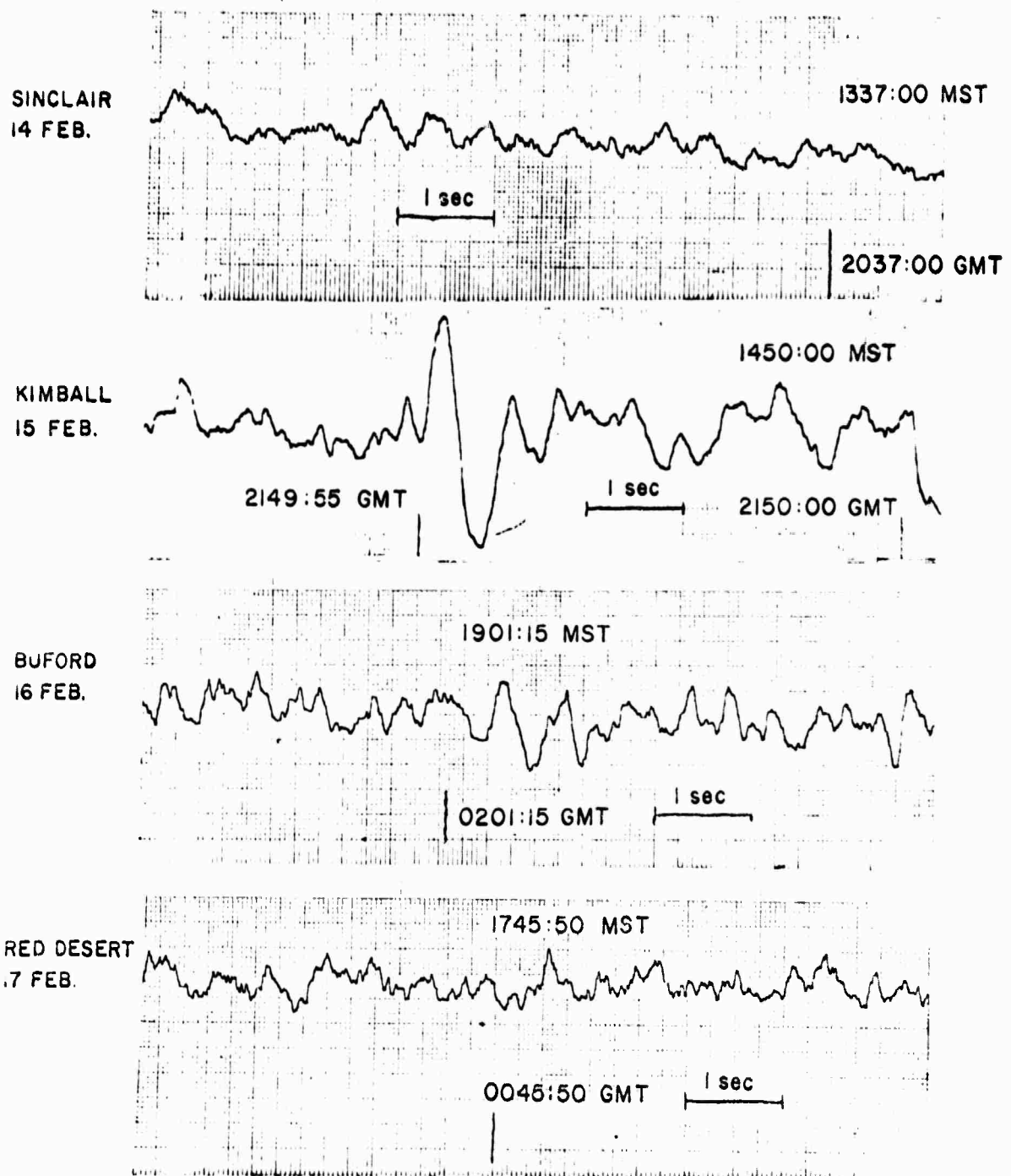


Figure 5.10

Observed fading, Prairie Smoke Ib, LOS over Platteville (U).

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## 6. DISCUSSION (U)

(S) In considering the results obtained from these initial experiments, it seems appropriate to structure the discussion according to the problems listed in Section 2 and Table 2.1.

### 6.1 Field-alignment of the Irregularities (U)

(S) The geometry of a satellite signal propagating through a field-aligned irregularity is illustrated in Figure 6.1.

Here,

$\epsilon$  = elevation angle of satellite =  $40.6^\circ$

$G$  = magnetic dip angle =  $67.9^\circ$

$\delta$  = magnetic declination =  $14^\circ$

$\theta$  = angle shadow axis west of north

It is easily shown from Figure 6.1 that  $\theta$  is given by

$$\tan \theta = \sin \delta / (\tan G \cot \epsilon - \cos \delta) = 7.2^\circ \text{ W of N.}$$

This formula will now be applied to the geostationary satellite results described in Section 4. Assuming that there is no velocity component parallel to the major axis of the pattern and assuming field alignment of the structures forming the pattern on the ground, the direction of the line of maxima on Figure 4.13 should be  $7.2^\circ$  north of east. In fact, values of  $\theta$  were observed ranging from  $4^\circ$  south of east to  $12^\circ$  north of east. The nearness of the  $\epsilon$  values to those predicted lends support to the idea that these irregularities are indeed field-aligned.

(S) A disadvantage of the geostationary determination of striation orientation is that a given striation can be examined only at one aspect angle (that corresponding to the satellite direction). Suitable use of an orbital satellite,

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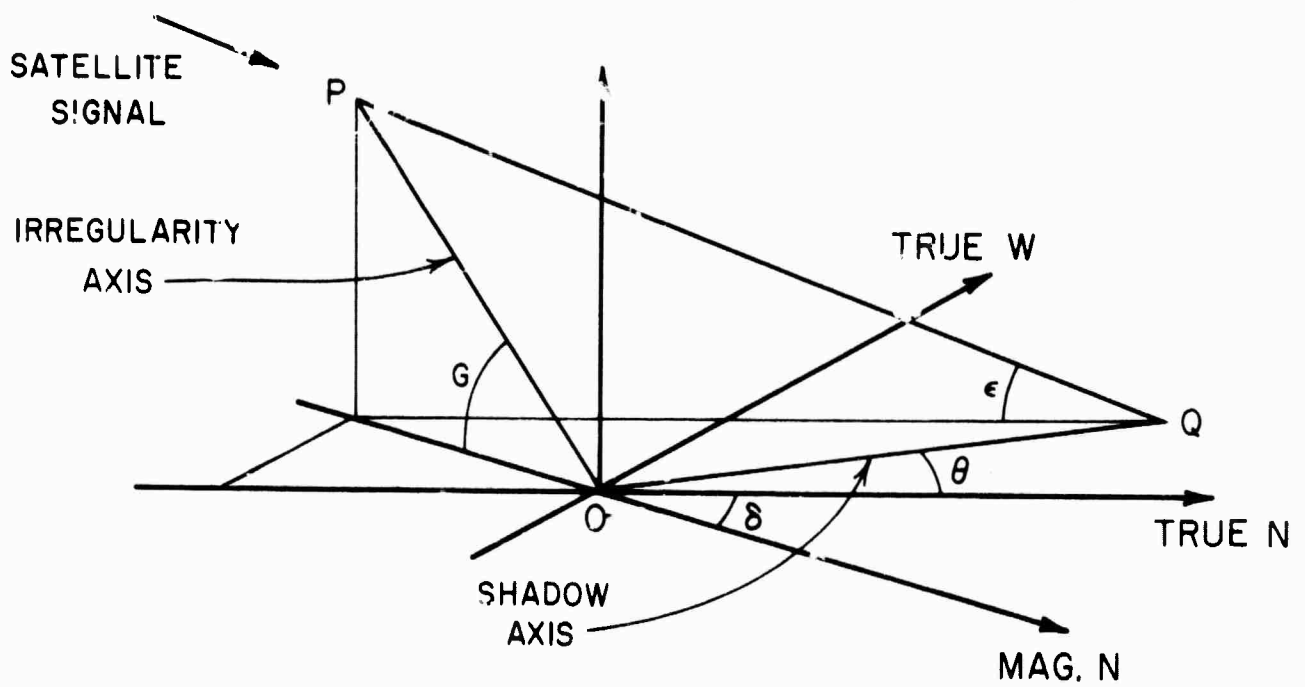


Figure 6.1  
Striation geometry (U).

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however, can give much more extensive information. Three antennas are properly necessary for this analysis.

(S) Observations at Buford, Wyoming during Prairie Smoke Ib used three antennas in a right triangle, with N-S and E-W spacings of about 75 m. Time shifts between the three antennas (Table 6.1) showed that the shadows of the scintillation irregularities were elongated between 47 and 67 deg west of north. Calculations based on field alignment show corresponding angles of 46 to 66 deg; supporting hypothesis of field alignment.

## 6.2 Structure Size of the Irregularity (U)

(S) The geostationary experiment gives the results for average spatial period shown in Figures 4.14 and 4.15; and the appearance of the fading encourages the belief that the appropriate form for the autocorrelation function is indeed Gaussian. The spatial period was found to vary by less than a factor of two throughout the day, between the limits of 300 and 600 m.

(S) Of course, the isotropy (or otherwise) of the structure in the north-south and east-west directions can be studied only by looking up the field line with three antennas. However, some deductions can be made from the limited two-antenna results of Section 5, and it is instructive to examine the fading shown on Figures 5.7 and 5.8 from this point of view. The similarity of the fading at the two antennas strongly indicates that the line of maxima is essentially straight (as would be expected at these relatively low elevation angles); and since the orbital satellite was almost due south at that time (see Figure 3.2), the striation axis was close to north-south (the exact angle will be calculated later). Therefore, the time shift between the two antennas is the same fraction of the period of the fading as the antenna separation is on the spatial period; leading to a spatial period of  $40 \times 1.33/0.12 = 440$  m, in good agreement with spatial periods found by the geostationary ex-

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Table 6.1

TIME MST 16 FEB. 72	SATELLITE		DELAY, msec		DEGREES WEST OF NORTH	
	ELEV.	AZIM.	N-S	E-W	MEAS.	CALC.
1900:58	56.8	166.6	35.0	30.0	47.6	46.0
1900:58	56.8	166.6	42.5	30.0	53.0	46.0
1901:01	58.8	166.3	40.0	22.5	59.1	49.1
1901:05	59.1	165.8	30.0	20.0	54.6	51.9
1901:10	60.5	165.0	35.0	17.5	58.2	57.0
1901:18	62.8	164.0	37.5	15.0	67.0	66.4

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periment (Figures 4.14 and 4.15).

(S) It should be emphasized that very-fine-scale structures (of about 1 m size) will be hard to detect using an orbiting satellite, as the velocity of the shadow of an irregularity at 300 km moves at about 3 km/sec over the ground, corresponding to a fade rate of 1 kHz for a 1-m irregularity. Such structures can be searched for using more sophisticated data processing, but could not be seen with the 200-Hz tracking filter bandwidth used.

## 6.3 Distribution of Irregularity in Altitude (U)

(S) As an illustration of the way the altitude of the irregularities may be deduced, consider the fading of Figure 5.8 described in Section 6.2. For the elevation angle of  $38.8^\circ$  at which the fading was seen, the shadow of a field-aligned irregularity would be seen at an angle (from the above equation) of  $5.0^\circ$  west of north (after correcting the angle  $\theta$  for the true satellite azimuth of  $181.1^\circ$  at that time).

(S) Now, the azimuth of the satellite motion was 2.35 deg west of north, producing a southward motion of the striation shadows in a direction 2.35 deg east of south. The apparent velocity of the lines of maxima would therefore be westward at a speed  $V \sin 2.65^\circ = .046 V_s$ . The apparent westward velocity observed was in fact  $40/0.12 = 330$  m/sec, giving  $V_s$  as  $330/0.46 = 7.2$  km/sec. The satellite elevation was changing at that time (from Table 3.1) by  $0.18^\circ/\text{sec}$ . The irregularity height (from simple geometry) can be found as 80 km, at a horizontal distance of 101 km, placing it in the D region directly over Platteville. Of course the precision of this calculation is not great, since the satellite direction was almost horizontal to the major axis of the striation shadows. A reasonable interpretation would be that the irregularity observed was in the E region (at about 120 km) directly up the field line from Platteville. To establish altitudes of irregularities, it seems best to locate the

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receiving station off to the side, thereby increasing the velocity at which the lines of maxima cross the antenna baseline.

(S) An example of this type of analysis is shown in the Prairie Smoke 1b results from Kimball (Figure 6.2), where the range of altitudes associated with the irregularities are given as a function of the satellite elevation. Evidently, the center of the irregularities is located close to overhead the heating transmitter.

(S) It is important to estimate the strength of the fluctuations in electron density in the ionosphere which produce the observed scintillations. Assuming that electron-density fluctuations with rms fractional fluctuation  $n$  and spatial period  $S$  are present throughout an ionosphere with critical frequency  $f_N$  and equivalent slab thickness  $T$ , the rms fractional amplitude scintillation  $F$  is given by

$$F = (\pi n f_N^2 / \lambda f^2) [TS \sin (G - \epsilon) / \sin \epsilon]^{-1/2}$$

where

$G$  is the magnetic dip angle

and

$\epsilon$  is the elevation angle of the geostationary satellite.

With  $f_N = 8$  MHz,  
 $\lambda = 2.2$  m,  
 $f = 137$  MHz,  
 $T = 100$  km,  
 $S = 400$  m,  
 $G = 67.9^\circ$ ,  
 $\epsilon = 40.6^\circ$ ,  
 $F = 0.1$ ,

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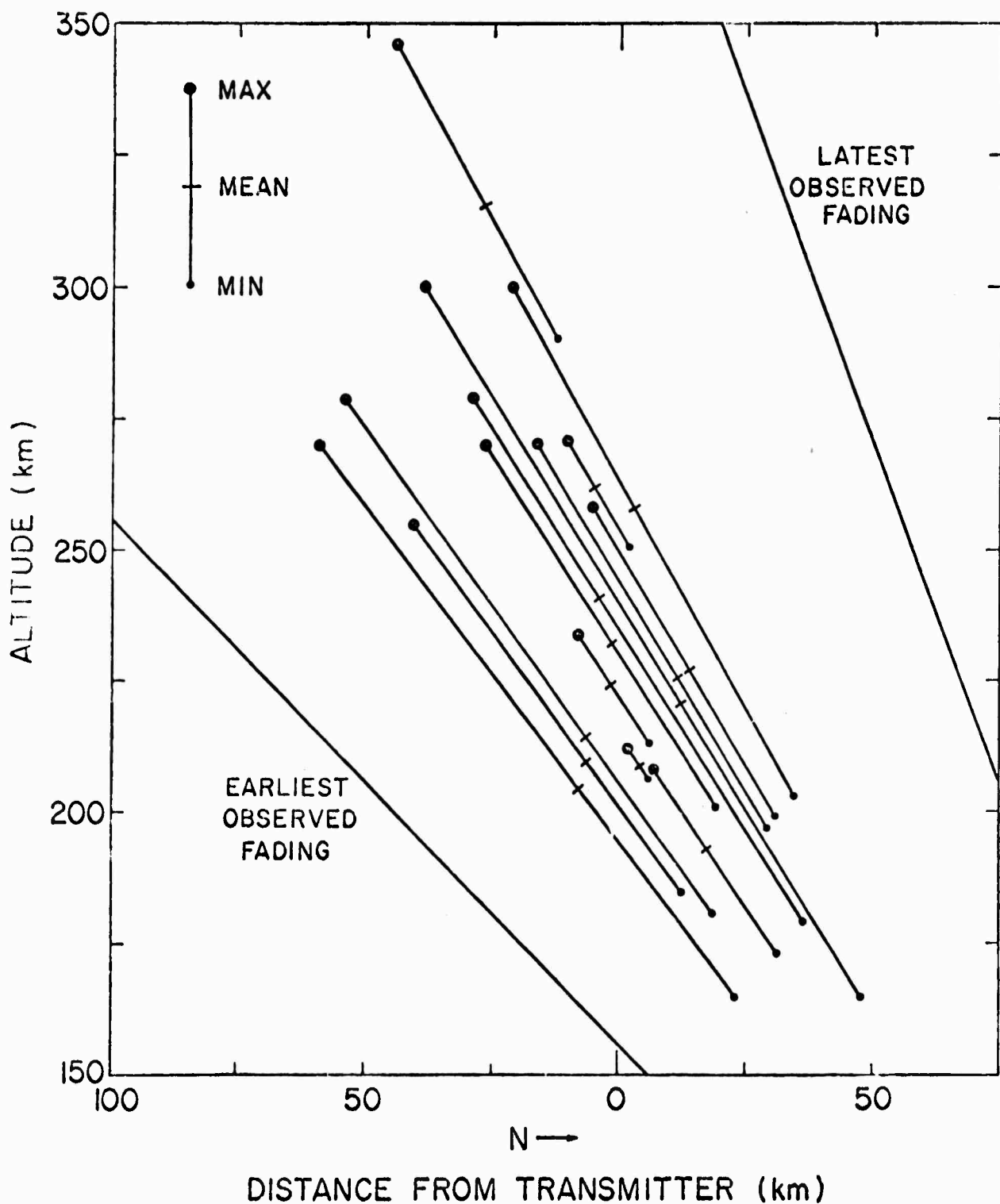


Figure 6.2

Observed height along lines of site from Kimball (U).

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the value of  $n$  is about 0.3%. Of course, a better estimate of  $n$  will be obtained from orbiting-satellite data looking upfield at 400 MHz frequency.

(S) The apparent discrepancy of Figure 5.5 between the observed elevation angle ( $71^\circ$ ) for rapid fading and the magnetic dip angle ( $69^\circ$ ) is best attributed to an in-line error in the satellite ephemeris. On this assumption, the rapid fading at 20:34:27 represents the effect of rapid southward movement of the 400-m structures seen on the geostationary experiment. It is evident that the period of these variations increases on either side of this time, reaching twice the minimum period at 20:34:25.12 and 20:34:27.63; a time difference of 2.51 sec. During this time the elevation angle (see Table 3.1) was increasing at  $0.33^\circ/\text{sec}$ . Now an ellipse with axial ratio  $L$  projects to an ellipse of 2:1 axial ratio when tilted at an angle  $\sqrt{3}/L$  radians; this should be just half the angular excursion  $0.33 \times 2.51 = 0.83^\circ$ . So  $L = 57.3 \sqrt{3}/0.415 = 240$ , and the irregularities are indeed highly elongated. Taking the width of each striation normal to the magnetic field as half the average spatial period of 400 m, the length of each striation is  $.2 \times 240 = 48$  km. Thus, the ASF irregularities evidently extend through the entire F layer, in agreement with the results suggested in Figure 6.2.

## 6.4 Horizontal Extent of Irregularities (U)

(S) Referring to Figure 3.1, it is evident that the geostationary locations at Lance Creek and Newcastle might have been expected to see rather similar fading characteristics. The small fading amplitudes observed at the Newcastle location would indicate that the line of sight passes through the "edge" of the modified region. At most times weak fading ( $I \sim 1 - 4\%$ ) was apparently recorded but with no similarity between the baseline fading patterns. This fact, coupled with the wide variety of time shifts recorded on the baseline, seems to indicate that many of the observed irregularities had a short life-

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time and a random motion. The assumption that spatial and temporal characteristics have the same form breaks down when such structures are present.

(S) The deepest fading and clearest cross-correlation was observed when the transmitter frequency was near foF2. Some increase in fading was observed on October 14 when the transmitter operated at increased power (1.5 MW).

(S) At Pine Bluffs, on the other hand, it is evident that the fading is much more intense and consistent. This leads to the suggestion that the region of disturbance is located over, and to the south of Platteville rather than to the north as has been assumed previously. In fact, the orbital results referred to in the previous section seem to indicate that strong irregularities are present directly up the field line from the transmitter, and there seems to be a strong case for orbital measurements at locations considerably to the south of Pine Bluffs. The results from Kimball in Prairie Smoke 1b (Figure 6.2) bear out this conclusion.

## 6.5 Onset and Disappearance of Fluctuations (U)

(S) The geostationary location at Lance Creek provided good information about the time response of the ionosphere. After turning on the transmitter there was usually a response within the first minute (Figures 4.5 and 4.6). Operating near full power, and with a frequency about equal to foF2, the transmitter caused fading within 20-30 seconds. Fading continued for 5-15 minutes following the transmitter being turned off. On several occasions a temporary increase in structure size and fading amplitude was observed a few minutes after the transmitter was turned off.

(S) The data collected on the morning of October 19 seems to indicate a smaller effect than that observed the following day. One possible explanation is a change in location or height distribution of the modified region. Differences because of time of day or day-to-day changes in ionospheric conditions

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are not well understood, and a larger data base is necessary to resolve them.

(S) There was a very pronounced change in the fading pattern at 1100 MDT on October 19 when the transmitter frequency was near  $f_oF_2$  and operating in the A mode (Figure 6.3). Large increases in fading amplitude and a rapidly changing structure size was often observed when the transmitter frequency was very near  $f_oF_2$ ; once below  $f_oF_2$ , the transmitter frequency seems a much less critical parameter. Fading was observed on October 20 when  $f_oF_2$  was as much as .75 MHz above the transmitter frequency. When  $f_oF_2$  went below the transmitter frequency, a greatly reduced effect was observed.

## 6.6 Drift Velocity (U)

(S) Since a geostationary satellite provides essentially plane-wave illumination of the ionosphere, the drift velocity of irregularity shadows on the ground is equal to the velocity of the irregularity in the ionosphere (unlike vertical-incidence measurements, where a factor of two is involved). Figures 4.10 through 4.12 show velocities in the range 25-125 m/sec, from west to east, in reasonable agreement with velocities found by vertical-incidence techniques. Detailed comparison of these two approaches will be of considerable geophysical interest.

## 6.7 Fading Variation with Frequency (U)

(S) From the fact that the depth of fading found when looking up the magnetic field line at 150 MHz was so great (see Figure 5.3), a higher frequency is definitely needed to ensure the validity of the shallow-screen approximation at all times. Accordingly, it is planned to examine future orbital satellites simultaneously at their higher frequency of 400 MHz, as part of Prairie Smoke II.

## 6.8 Angle-of-arrival Scintillations (U)

(S) The phase fluctuation for the 400-m irregularities is essentially equal

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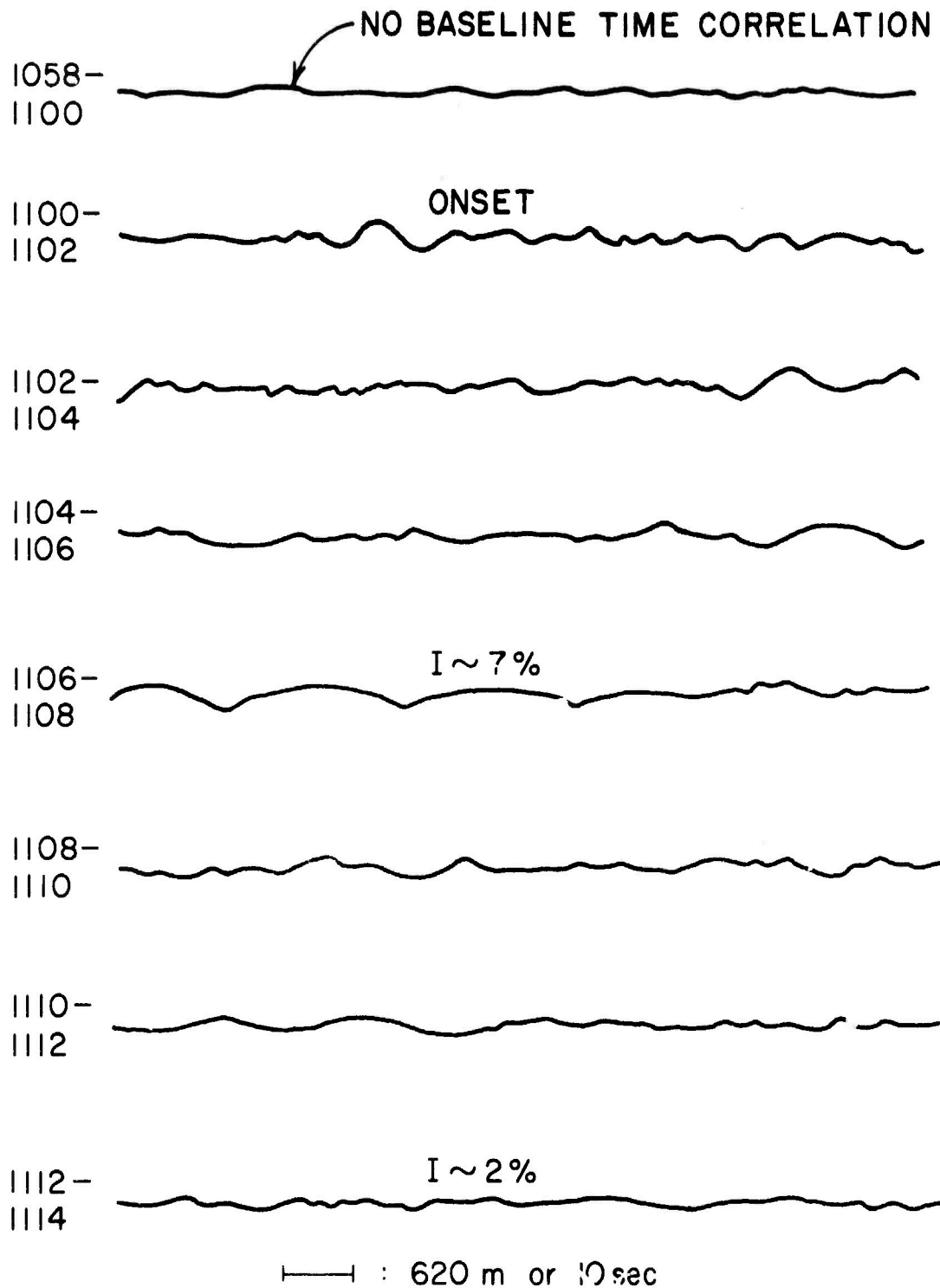


Figure 6.3

Anomalous fading behavior, 1508-1114 MDT, October 19, 1971 (U).

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to the phase fluctuation in radians at the ground, or approximately 0.2 radian. This corresponds to an angular deviation of about 6 milliradians at 150 MHz for the geostationary location. However, at Pine Bluffs the fluctuation is evidently much greater, and phase measurements will be needed to determine its precise value.

## 6.9 Multipath Effects (U)

(S) On several occasions during Prairie Smoke Ib, a Fresnel-like diffraction pattern was observed from an orbital satellite; an example is seen of Figure 6.4 for Kimball on February 15, 1972. These diffraction patterns, which show similarly on the spaced antennas, probably arise from specular reflection from sharp field-aligned gradients of ionization.

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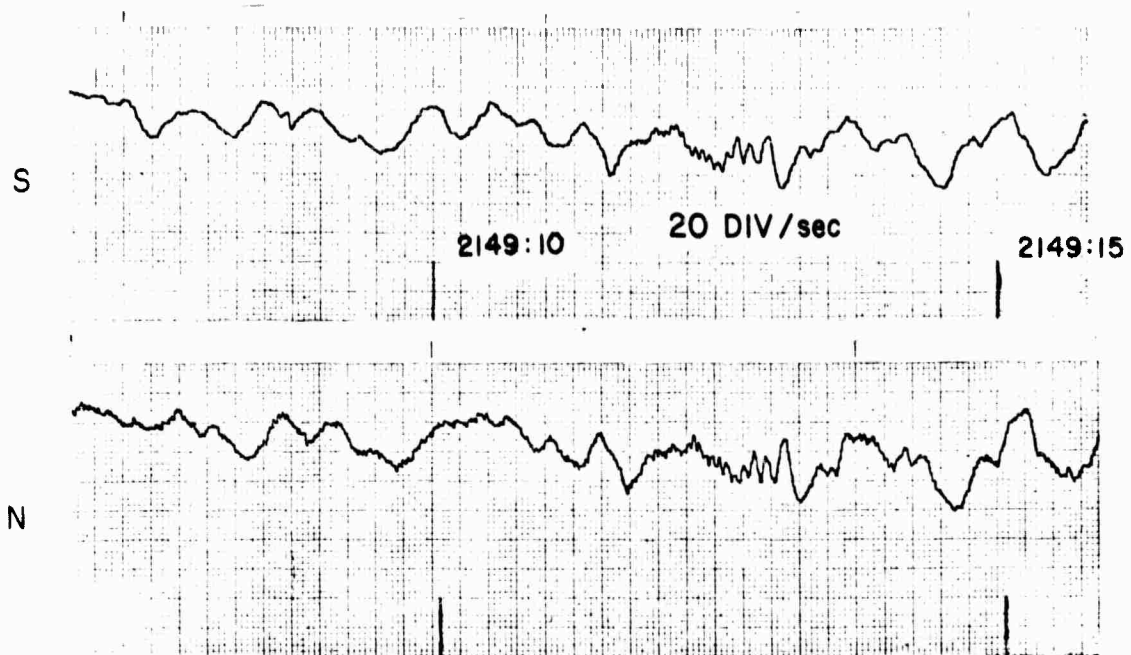


Figure 6.4  
Orbital fading at spaced antennas showing multipath (U).

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## 7. CONCLUSIONS (U)

(S) It is evident that the frequency chosen for the geostationary experiment is close to optimum, in that shallow but appreciable fading is observed. For the orbital experiment the upfield fading is so intense at 150 MHz that a higher frequency of 400 MHz will be required as well.

(S) Normal scintillation is seen with about one percent RMS amplitude, about 9 sec; on heating, the scintillation is enhanced to four to ten percent RMS at the geostationary location, with about 6 sec period. The fading appears fully in about 1 min and disappears in 5 min; during the latter time, the structure size apparently increases by a substantial factor.

(S) The spatial frequency of the predominant structure appears to be about 400 m, apparently perfectly field-aligned, and moving towards the east with velocities of 25 to 125 m/sec.

(S) The structure appears over a radius of about 100 km, apparently centered on a region upfield from the heater transmitter (rather than to the north).

(S) The irregularities seem to occur down to E-region heights, though this is subject to further investigation.

(S) The fading observed from an orbital satellite seems to occur at elevations slightly higher (by one or two degrees) than the directly upfield direction; the reason for this is not apparent.

(S) The electron density fluctuations apparently have an rms fractional fluctuation of about 0.3%, and extend to about 50 km through the F layer.

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13. ABSTRACT  (S) During October 1971, as part of Prairie Smoke I, measurement were made of signals transmitted through the artificially heated layer over Platteville from a geostationary satellite at 137 MHz; the morphology and motion of the artificial spread F (ASF) irregularities were deduced by spaced-receiver measurements of that signal. Similar information was gathered in December 1971 and February 1972 (Prairie Smoke Ib) using orbital satellites to give the altitude and orientation of the irregularities. Preliminary results only from Prairie Smoke Ib are included in this report.			

KEY WORDS

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LINK B

LINK C

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morphology of artificial spread F